MANUAL OF METHODS FOR FISH STOCK ASSESSMENT

PART III. SELECTIVITY OF FISHING GEAR

by

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PREPARATION OF THIS PAPER

This technical paper forms an integral part of the FAO "Manual of Methods for Fish Stock Assessment". It updates the first version published in 1966 and includes further detailed information on gear and hook selectivity. The original paper was based on the report of the ICES Mesh Selection Working Group, 1959-1960, of which the first author was convener. The present revised version has been reproduced primarily for use at FAO and FAO executed field projects and fishery resource surveys and for limited distribution to specialists actively engaged in gear selectivity work. The final revision which will be printed in the FAO Manual Series will take account of experience in the use of the present version and will further incorporate advances in this field of research.

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PREAMBLE

Selectivity is important to fisheries, and studies of selectivity need to be made by fishery scientists for two broad pu: oses. Firstly scientists can rarely study fish populations directly, and have generally to rely on the analysis of catches made by the commercial fishery, or by research vessels. The size or age composition of these catches, with, at least over some range of size or age, is rather similar to that of the actual population. Changes in the catches, e.g., a decrease in average size or age, can therefore be used as a guide to changes in the population, e.g., as evidence of an increase in total mortality due to increased fishing. Knowledge of the selection by the fishery can make these studies more quantitative and more valuable.

Secondly, control of selectivity is an important management tool. Reducing the fishery mortality on certain classes of fish (typically small fish with the potential capacity to grow to a much better size) can give appreciable long-term benefits to the fishery, at the cost of some short-term ton of small fish. A good knowledge of the selectivity of the fishery is necessary to determine what measure (closure of certain mercury areas in which small fish are abundant, prohibition of a particular type of gear, or the use of nets, with meshes smaller than a certain size) would be needed to achieve the desired result.

The Nature of Selectivity

In the wide sense outlined above, selectivity can be considered as any factor that causes the size composition of the catch to be different from that of the population. Put another way it is anything that cau'es the fishing mortality to vary with size (or age, or, indeed, any other characteristic of the fish). Such differences can arise in many different ways, but can be rightly classified accordingly into three groups:

(a) differences in the area or time fished,

(b) differences in the probability of fish of different sizes encountering the gear,

(c) differences in the probability of fish of different sizes being returned by the gear, once they have encountered it.

Large-scale differences in the sizes of the fish occurring in different places or at different times of the year can be taken account of by suitable methods of analysis, e.g., by stratifying the sampling stations for research or survey vessels. The theoretical and practical difficulties in dealing with non-uniform distribution of fish of different sizes and of commercial or other fishing, can be considerable, but will not be dealt with in the present manual.

Within an area, there can be big differences in the probability that fish of the species, but of different sizes (or ages, or sex, etc.) will encounter a given unit of gear. Large fish may swim faster and cover a wider area, so be more likely to meet static gear such as gillnets, longlines or traps. On the other hand, they may be more wary or more active and thus be more likely to move out of the path of a trawl before it reaches them.

Differences can be quite subtle. For example, within a school of pelagic fish the smaller fish are often nearer the surface than larger fish, so that a mid-water trawl select in favour of large or small fish depending on the precise depth at which it fishes. Large yellowfin tuna are more closely associated with porpoise schools than small fish, so that the development of the use of porpoise schools in purse seining for time involved, other things, a shift in the effective selectivity of the fishery toward larger fish.

The best known form of selection concerns the escape of fish from a fishing gear they have encountered it. Familiar examples are the passage of small fish through the of a trawl or gillnet or of small lobsters through escape gaps in a lobster pot, or

the failure of a small-meshed gillnet or small hook to retain a large fish. The occasion when a whale gunner refrains from firing at a small whale when it is seen to be undersized can also be considered as a form of selection in this sense.

Some of this selection is quite obviously determined by a simple physical feature of the gear. A fish that is too big to get its head into a gillnet, as far as the gill-cover, is unlikely to be retained by the net (though if it has a lot of spines it may become entangled). Equally few fish small enough to slip easily through the cod-end meshes of a trawl will be retained by the trawl. Other types of selection are less obvious. Different types of gear, e.g., trawl, Danish seine and bottom longline can produce catches very different in species composition, and in the size composition of particular species even when fished close together at the same time. Even for a gear of a given type, e.g., bottom trawl quite minor changes in the way that the gear is rigged can cause marked differences in the species and size composition of the catches (Margetts, 1949 a, 1956). It is clear that the selectivity of a trawl is not determined wholly by the proportion of fish that escape through the meshes, but the differences in the behaviour of fish of different sizes, as they come into contact with the gear, must be taken into account. This form of selectivity can occur for fish that are too large to pass through the meshes.

The tactics and preferences of fishermen are particularly important in determining selectivity in the case of active techniques such as purse seining. A large purse seine made of moderate or small meshes is less relative than most other gear. However, among most species of pelagic fish there is a strong tendency for fish of the same size to shoal together. By choosing which school to shoot his net on, a fisherman can be highly selective toward one or other size of fish.

Selectivity is not only a function of the size of fish, though this is the commonest and most important aspect where the behaviour of the animal determines whether it gets caught, e.g., whether or not it takes the bait, then other characteristics such as maturity stage may be important. For example, crabs and lobsters may not enter traps put after moulting, and catches in traps may completely misrepresent the preposition of the total population that is newly moulted.

<u>The Mathematical Expression of Selection</u>

Selection as discussed above is concerned with the pattern of changes, between different sizes (or ages) of fish in the proportion of the actual stock caught and retained by a particular fishing operation, i.e., the fishing mortality caused by that operation -- whether it is the whole commercial fishery during a season, or one haul by an experimental net used by a research vessel. Ideally, therefore, selection should be expressed by a function relating fishery mortality to size of fish, as is done by the direct method of measuring the selectivity of gillnets (see section 4.6.1.).

Mathematically, we can write, for a given size of fish i, and a given type of gear j, exerting a fishery effort f_j,

F_{ij}, the fishery mortality $= q_{ij}\, f_j$

and the form of the selectivity for the j^n gear can be illustrated by plotting q_{ij} against the size.

In practice it is difficult to measure q_{ij} in absolute terms, but relative measures can be obtained. For example, if another gear exerts an effort f_k, and the catches of the two gears, of fish size i, are given by N_{ij}, N_{ik} respectively, then we can write,

$$N_{ij}/N_{ik} = F_{ij}/F_{ik} = q_{ij}/q_{ik} \times f_j/f_k$$

in which the final part is independent of the size i. That is, by using the ratio of the catches by the two gears, the selectivity of one relative to the other can be determined. If one gear is assumed to be nonselective, i.e., q is assumed constant, at least over the range of sizes of immediate interest, then the relativity of the other gear, at least in relative terms can be determined. For example it is often assumed that a small-meshed trawl is nonselective for all fish that are too large to pass through the meshes. The selectivity of larger-meshed trawls can then be determined as the ratio of the catches of the two trawls. A special case of selectivity, and of presentation of selectivity experiments occurs when the only form of selectivity is the escape from inside the gear, e.g., through the meshes of a trawl. Then selectivity can be defined as the proportion of fish of each size that escape and this percentage can be plotted against length (see Figure 1). Mathematically this is equivalent to putting q_{ij} = constant = 1 for those sizes completely retained by the gear.

Scope of this Manual

Selectivity studies potentially cover a very wide range of techniques - detailed methods of rigging fishing gear, studies of the behaviour of fish, and as regards the use and interpretation of results, aspects of fish population dynamics, and of the economic, legal and other aspects of the choice and enforcement of fishery regulations. They also could concern all types of fishing gear. The development of selectivity studies in these different fields has been extremely uneven. Overwhelmingly the work has been concerned with two major aspects - selection through the cod-ends of trawls (and also Danish seines), especially in the North Atlantic, and, to a larger extent, gillnet selection especially in fisheries for salmonids. It has not, therefore, been possible at present to produce a manual that is equally helpful for all situations. Inevitably greater attention is given to trawl cod-end selection, where the experimental and analytical techniques are better developed. For those needing to determine the selection of a trawl, a fairly extensive description is given of how the experimental work should be carried out, and how the data arising from that work should be analysed and presented. In doing this it has been possible to draw upon the long experience of the two North Atlantic bodies, ICES and ICNAF. There is no corresponding volume of work and published reports to draw upon for other aspects of selectivity. Mention is made of other types of selection - by gillnets, traps, hooks, etc., as well as of the selectivity arising from the behaviour of the fish rather than of the physical characteristics of certain parts of the gear, and it may be emphasised here that anyone concerned with the practical aspects of selectivity should always be aware that these, less easily observed aspects, may always be as important as those that can be measured by the techniques discussed here. However, for the present it is not possible to discuss them in detail. To that extent this manual shall only be considered as provisional. It is viewed as another step toward achieving better understanding of the selection process in fisheries throughout the world.

C O N T E N T S

1. INTRODUCTION

Chance plays a big part in the capture of fish from a natural population. If any one individual were as likely to be captured as any other, and if the capture of an individual were not dependent in any way on those already captured, the method of capture would be nonselective. Processes which cause a departure from this situation are defined as selective ones. It is a characteristic of most fishing operations that they are selective, with the result that the catch is not representative of the population as a whole in one or more of its aspects, and the effect of the method of fishing on the population is not uniform over all sub-divisions of the population. The selectivity of any method of capture depends on the type of gear employed, the way the gear is operated, where and when it is used and the behaviour of the individuals in the population, that is, on factors both intrinsic and extrinsic to the process of capture, and on the interaction between these.

1.1 Selection by the Fishing Gear

The way in which selection of fish occurs, and the degree of selectivity for any fishing gear, both vary according to environmental and ecological conditions and according to practical and mechanical features of the fishing process. Controlled comparative fishing exercises and the comparison of catches of commercial vessels fishing in one locality both illustrate how selective fishing can be.

When the same fishing gear or different types of gear are used at sometimes only slightly different depths in the water the catches from the different levels can be markedly different both in their species composition and in the size compositions of the species caught. An example of this is shown in pelagic trawling for sprats, when two trawls are both at the general level of the shoals; if one is towed slightly deeper than the other it will often catch a greater proportion of bigger fish. Another example, again in pelagic trawling, is where several species are available, and a small variation in depth of fishing very substantially alters not only the quantity of fish caught but also the species composition of the catch, some species that are abundant in one catch being not even represented in the other. These two examples both illustrate how selection can be made by the gear because of features of the distribution and behaviour of the fish. But even in one delimited habitat, say on or close to the sea bed, species selection is shown between widely different gears, e.g., a trawl and lines fished on the same ground at the same time will take very different proportions of the species available, and between only slightly different gears; e.g., a trawl and the same design of trawl slightly differently rigged, when fished side by side, have been shown to produce catches with quite different absolute quantities and relative proportions of roundfish, flatfish and zoobenthos (Margetts, 1949 a and 1956). Inspection of the length distributions of any one species caught by different gears, e.g., trawl and seine, with the same net mesh size and fished simultaneously on the same ground also reveals differential fish size selection between the gears (Margetts, 1949 b). Both species and size selection can be varied in bottom fishing on any one ground by altering the mode of operation of the gear, for instance, in trawling by towing at different speeds, or in seining by using the anchor and fly-dragging techniques. From such examples and considerations, it is clear that even a bottom trawl which released nothing would not necessarily sweep up everything in its path.

Probably the least selective of fishing gears is the purse seine of very large overall size and with small meshes, but even from this, some species of fish will escape more easily than will others, so that it is not truly nonselective, especially between species of fish. Furthermore, the use of a purse seine is restricted to pelagically shoaling fish and, being essentially an aimed fishing technique, cannot, by itself, be used to take quantitative samples of fish. In open water, even such fishing methods as the use of explosives and poisons are still selective for, although they may kill or stun (either totally or partially according to range and concentration), as a result of their action different species either float or sink and this feature, together with the method of collection of the fish, introduces selection.

It is noteworthy that in some of the cases of selection by gear an element of mesh selection is involved because very large meshes set at a suitable angle of attack in forward parts of, for instance, trawls, are used to direct fish into the net; this they will do for some species more than others.

1.2 Size Selection within Gear

Some fish, coming in contact with or into some gears are, by virtue of their size and swimming ability, able to escape from them; this is a part of gear selection as in 1.1 above. Size selection within a gear, as meant here, includes mesh selection and hook selection. Mesh selection is the selection of size of fish by the ability of the fish to pass through or be held by the net meshes. Hook selection is the selection of sizes of fish by the ability of the fish to take the hook and bait and of the hook to hold the fish.

1.3 Scope of this Manual

A knowledge of gear selectivity is necessary both in choosing or designing a gear for a particular fishery or investigation and in many fish stock assessments. The latter may include the determination of the real fish population by way of calculation from fisheries statistics and sample fishings, when the need is to know what a particular gear catches out of a population, or it may include the determination of the effects on stocks and yields of a change in gear regulations, e.g., of minimum mesh size. At present, although research on the subject is advancing, especially by the use of sophisticated acoustic apparatus and techniques counting and observing fish in the zone of action of gear, and by considerations of the parameters of various gears which control the quantifying of fishing effort (Treschev, 1971), selection by the fishing gear cannot be expressed quantitatively with any assurance. But selection within a gear can be measured. This manual, therefore, is concerned almost wholly with describing and evaluating techniques for studying and measuring size selection of fish within a gear; because so little information on hook selection and its measurement has been collected, the main emphasis is on mesh selection.

2. SIZE SELECTION

2.1 Mesh Selection

The ability of a fish to escape through or be held by a mesh during fishing depends on its dimensions in relation to the opening of the mesh. For roundfish the relevant dimension is the maximum girth and this will be either the head girth or the maximum body girth at the time of capture. For flatfish the relevant dimension will be related to the breadth of the fish. These dimensions are highly positively correlated with the length of the fish and so the ability of a fish to escape may be regarded as being dependent on its length, although the dependence is not direct. Thus because of the ease with which fish lengths can usually be measured, it is customary to relate selection directly to length rather than to any other dimension.

If all fish whose maximum girth was less than the mesh size passed through the net wall while all fish whose maximum girth was greater than the mesh size did not pass through, the selection of the fish in relation to girth would be "knife-edged"; that is, either all fish of a certain size (as measured by girth in this case) would be held by the net, or none of them. Selection, even in this idealised situation, would not be knife-edged in relation to fish size as measured by length, for not all fish of the same length have the same girth. Furthermore, in practice, most nets, especially those which are braided by hand, contain a range of mesh sizes. These factors alone would result in a retention pattern exhibiting a gradation in probability of retention with girth and length. The relationship between the probability of retention and the length, when presented graphically, is termed the length selection curve. The first aim in evaluating the selectivity of a net is to estimate in a precise manner the length selection curve.

2.1.1 Trawls and Danish Seines

The inherent selectivity of trawls arises mainly from the ability of some fish to pass through the open meshes of the netting. Escape of fish through the meshes can take place in any part of the trawl, but experimental evidence suggests that the most important area of escape is in the cod-end.

Because of the wide employment of bottom trawls by countries with highly developed fisheries, most of our present knowledge of selectivity relates to fishing gear of that type.

A typical length selection curve for the cod-end of an otter trawl is shown in Figure 1. To obtain this curve the proportions of fish at each length entering the net which are retained by the cod-end have been plotted against length. Because of various factors, all of which make for a departure from the ideal knife-edge selection, the selection curve for a trawl cod-end is sigmoid in shape; these factors include: variation of the length, girth ratio of the fish, variation in manufactured mesh size, change in size of meshes in different parts of the cod-end (caused by uneven loading in use), blockage of some meshes by accumulated catch, and variation in liveliness of the fish, some of which may have been tired out by the catching process. For any particular cod-end of a uniform mesh size, if the percentage of fish at each length of fish is plotted against fish length the curve rises in an "S" shape from 0 percent retained (at a length at which all the fish are so small that they pass through) over a range of fish lengths to 100 percent retained (at a length where all the fish are so big that their passage through the meshes is impossible). The curve is usually symmetrical and is a close approximation to the integral of a normal curve or to the logistic curve.

A very convenient and useful way of putting a value to the selectivity of a cod-end is by reference to the 50 percent point of the selection curve or the 50 percent selection length. This for any one mesh size and fish species corresponds to the fish length at which half escape through the cod-end meshes and half are retained. If the selection curve is truly symmetrical it will be so about the 50 percent point, which will then also represent the mean selection length. For some purposes, especially in stock assessments, when the two

are not coincidental because the selection curve is asymmetrical, the mean selection length will be more applicable than the 50 percent selection length. This mean selection length can be calculated by equating areas to either side of it, above and below the curve, as described by Gulland (1969).

The sharpness of selection is indicated by the range of length of fish between the 25 and 75 percent retention lengths on the selection curve. This is referred to as the selection range. It will be noted that the selection range is not defined in terms of the 0 percent and 100 percent retention lengths. These points are not easy to determine graphically, and for some curves specified in precise mathematical terms (e.g., the normal ogive and logistic curves) have always the values - infinity and + infinity.

It has become standard practice to specify the length selection curve in terms of the 50 percent retention length and the selection range. For most purposes, these together adequately describe the curve. Cod-end selection curves are nearly always symmetrical about the 50 percent length.

Selection factors: the effect of increasing the mesh size of a trawl or Danish seine cod-end is to increase the percentage escapes at each length. Surveys of existing selectivity data have shown that, in general, over a wide range of cod-end mesh sizes the relation between the 50 percent retention length and the mesh size is approximately linear. Empirical relationships for several species are given by Jensen (1949), based on the data available at that time. Summaries of data for haddock and redfish (Sebastes) are also provided by Clark (1957 a) and Clark, McCracken and Templeman (1958). The International Council for the Exploration of the Sea (ICES) has published a great deal of collected data from trawl and seine mesh selectivity experiments in its Cooperative Research Reports, Series A. Numbers 2 and 25 (1964 and 1971).

Where sufficient data have been collected to determine a relationship, it has been found in almost all cases that the 50 percent retention length is sufficiently nearly proportional to cod-end mesh size for a proportional relationship to be applied in practice. The constant of proportionality has been termed the selection factor, thus:

$$\text{selection factor (s.f.)} = \frac{\text{50 percent retention length}}{\text{mesh size}}$$

where both quantities on the right-hand side of the equation are in the same units of measurement. The selection factor is thus a dimensionless quantity, its value varying with the species of fish and also with the cod-end material, twine construction, catch size, etc. (see Section 5). Selection factors obtained for trawls from experiments in North Atlantic waters have been found to lie mostly between 2.0 and 5.0.

Clark (1957 b), in experiments on the selectivity of silver hake (Merluccius bilinearis), found quite large differences in the selection factors for cod-ends of the same material but of different mesh sizes; he took these results as indicating that it may not be sufficiently accurate in all cases to regard the 50 percent retention length as directly proportional to the mesh size for all species. Although no relationship between selection factors and mesh size has been reported by other workers, it is advisable, before employing selection factors for the description of cod-end selectivity, to test whether they vary with mesh size.

Because of the proportionality between 50 percent retention length and mesh size and also between length and girth of fish, if a selection factor for a specified fish and mesh type is known then, if needs be, an approximate prediction of the selection of another species of fish by any particular size of mesh in the same type of gear can be made, tentatively, via adjustment of the selection factor according to the relative girths at length of the two species. Such estimations should always be treated with due reserve and should be checked by experiment as soon as possible; although the method works reasonably satisfactorily between some species, there is some evidence that between others it fails.

2.1.2 Gillnets

Whereas trawls and seines envelop fish in bags, gillnets hold fish stuck in meshes. A mesh can hold a fish in one of three ways:

(a) Wedging - Fish is held tight by a mesh around the body,

(b) Gilling - Fish has entered a mesh and cannot back out because the mesh is caught behind the gillcover,

(c) Tangling - Fish has not necessarily penetrated a mesh but is caught in the net by teeth, maxillaries or other projections.

For any particular mesh size, fish of some optimum size are held most securely; smaller or larger fish are less likely to be caught. Very small fish can go right through and very large fish cannot penetrate deep enough into a mesh to become stuck. Gillnet selection is sharp, i.e., the size range of fish in the catch is narrow. Baranov (1948) suggested that only 2-3 percent of maximum selectivity remains for fish whose length differs from the optimum by 20 percent.

A typical gillnet selectivity curve is bell-shaped, falling to zero on both sides of a maximum (Figure 2). It is described by its mode, width, height and shape. The mode corresponds to the optimum length of fish caught; the width to the selection range. (Note the different meaning from "selection range" of trawls described in 2.1.1. For a curve with very long tails, selection range can be taken as the range over which selectivity is at least 5 percent of the maximum.) The height describes how efficiently the mesh catches fish of the optimum length; the shape varies according to several characteristics of net and fish.

The approximate features of a selectivity curve can be predicted from the shape and relative dimensions of the species of fish. The simplest case is smooth-bodied fish that lack prominent teeth, maxillaries or spines whereby they would be easily tangled. To be wedged or gilled, the fish must penetrate a mesh beyond their gillcovers but be unable to pass through, therefore their selection range is the length range for which the head girth is smaller but the maximum girth larger than the mesh perimeter. The selectivity curve is unimodal and may be symmetrical; for most species the mode is at the length for which the maximum girth is about 1.25 times the mesh perimeter.

The foregoing applies to fish that are subject only to "fair captures" by wedging or gilling. The selectivity curve is more complicated for species that are often tangled or caught behind maxillaries in a way analogous to gilling. Small fish still escape through the mesh but now large fish can be caught "by their noses" even though their head girths are too large to allow penetration into a mesh. As a result, the selectivity curve becomes broader and skewed to the right (McCombie and Berst, 1969). Because most species of fish can be tangled, such skewed-to-the-right selectivity curves are the most common. The right slope of the curve represents large fish that are tangled; the left slope, small fish that are wedged; the shape of the left slope is affected by variations in girth due to nutritional state or sexual ripeness (Ishida, 1969). When captures other than by wedging or gilling are prominent, the selectivity curve may have two or more modes.

The description and comparison of selectivity curves is made easier by approximating them to some mathematical distribution. Symmetrical unimodal curves are usually described by the normal density function; skewed unimodal curves by "skew-normal" variants of the normal curve (Regier and Robson, 1966). The latter may also be described by treating the left and right limbs as separate cumulative normal distributions (Sechin, 1969 a; Kawamura, 1972). Multimodal curves can be resolved into simpler unimodal component curves, one for each major way of capture (Hamley and Regier, 1973).

In comparing selectivity curves of different mesh sizes, their most useful features are the modes and heights; the shapes and selection ranges remain similar for all meshes. The mode l_o is approximately proportional to mesh size:

$$m = Kl_o$$

where m is the bar measure of mesh, and the proportionality constant K is called the "selectivity factor" (note the different meaning from "selection factor" of trawls described in 2.1.1). The value of K varies from about 0.10 for slim fish like mackerel to about 0.20 for tall-bodied fish like bream (Baranov, 1948). Within a particular species, K varies with plumpness, as between immature and ripe fish.

Heights of selectivity curves were long assumed to be the same for all mesh sizes, but recent experiments show that the heights increase with increasing mesh size (Hamley and Regier, 1973)

2.1.3 Pots

Mesh selection in pots can be considered as a case of selection by either preventing or allowing passage through an opening and thus many of the considerations of cod-end selection as in Section 2.1.1 above are applicable. The mesh is generally rather rigid, for example, of wire netting, and even when made of the same materials as are trawls it is held on a frame which limits distortion of mesh shape. Pots of material other than netting, such as wicker or moulded plastic, have openings of designed size which, although not diamond mesh shaped, control the retention and escape of fish or shellfish according to their size. Therefore the selection curve for such gear will be of the sigmoid type as for trawls.

2.2 Hook Selection

Hook fishing is selective to species of fish, taking only those attracted to bite at the bait or lures. Within a species, size selection occurs because small fish cannot take a hook in the mouth and large fish are not held securely by small hooks; thus larger hooks tend to catch larger fish. Hook selectivity curves are similar to those of gillnets, but have wider selection ranges; published curves suggest that some 20 percent of the maximum selectivity remains for fish 50 percent shorter or longer than the optimum. Whereas gillnet selectivity depends on mesh size, hook selectivity depends on gape of the hook (Figure 9); possibly the modes of hook selectivity curves are proportional to the gapes.

Very little work has been done on hook selection. Because of the wide selection ranges and relative scarcity of very large fish, the right limbs of hook selectivity curves are often difficult to demonstrate. Thus McCracken (1963) and Saetersdal (1963) reported that hook selectivity curves to cod are one-sided, like trawl selectivity curves. Their method of estimation may have masked the presence of an upper selection range; they compared longline and trawl catches and assumed trawls to be unselective for large cod; if, in fact, trawl selectivity decreases for cod above the size of maximum retention, longline selectivity to large fish was overestimated. (Note that longline and gillnet selectivity is estimated as the proportions of fish taken from each size class in the population; trawl selectivity as the proportions of fish retained from those that enter the cod-end.) Holt and Thomas (1957) obtained a peaked, lognormal hook selectivity curve by comparing catches of cod in longlines and purse seines. This may be the most reliable estimate of hook selectivity to date, as purse seines may be more nearly unselective for large cod than trawls are. Koike et al.(1968) and Takeuchi and Koike (1969) also obtained two-sided though flat-topped hook selectivity curves, using an "indirect" method of estimation developed by Ishida (1962) for gillnets.

3. EXPERIMENTAL METHODS

3.1 General Considerations

3.1.1 Which particular measurements of selectivities should be made and thus the procedures for making them should be governed largely by the use for which the information is required. For instance, the need may be to make a purse seine for a particular fishery in which case a prerequisite for the design is a knowledge of the maximum site of mesh that can be used without meshing the small fish; this means identifying the fish length at which the sigmoid or left-hand side of the gillnet selection curve rises from 0 percent retained. Another example is where the need is in fish conservation considerations to assess the effect of a trawl mesh regulation change; this requires precise evaluation of the shape and slope (i.e., the selection range) of the selection curve and of the 50 percent retention length.

3.1.2 The choice of method to be used in a selectivity measurement experiment will be governed by the type of gear involved, e.g., the particular type of net, or lines, or pots, and by the facilities, e.g., ships and time available.

3.1.3 All experimental methods involve: a - measurement of the dimensions of the selecting part of the gear, e.g., hook size, mesh size; b - measurement of fish caught; c - recording of experimental conditions, e.g., time, gear, speed, total catch, etc.; d - usually a series of observations in an extended period of fishing under commercial fishery conditions; e - comparison of length distributions of catches by two or more different nets, sets or types of gear; f - relation of differences between length distributions to the experimentally controlled variables in the fishing gear, and g - assessment of the significance of the relationships between gear and fish sizes observed.

3.1.4 All experimental methods are a form of comparative fishing and as such are subject to the errors inherent in comparative fishing (Margetts, 1969). Comparative fishing involves the examination of the effects on catches of controlled variables amongst a number of uncontrollable or partially controllable variables. The design of a selectivity measurement experiment should be such as to minimise the number and effects of these variables which tend to obscure the results.

When several different gears or variations of the same gear are to be used, the order of fishing them has to be decided. If experimental conditions are at all likely to vary during the period, it is essential that any differences detected in the comparisons be attributable to differences in the gear and not be undistinguishable from differences due to external factors which have not been controlled or which cannot be controlled. Although it is necessary to make estimates of differences from results obtained under as uniform conditions as possible, it is also very desirable that comparisons should cover a wide range of practical conditions in order to provide for a wide applicability of the conclusions from the experiment. Both these requirements can be met by dividing up the whole time available into periods within which experimental conditions are kept (or, if they cannot be controlled, are likely to be) as uniform as possible, making changes which result in (or are likely to result in) changes in experimental conditions only at the end of each experimental period. For instance, if the length selection curve of a cod-end is to be determined by the covered cod-end method and simultaneously the effect of the cover on escapes is to be assessed, hauls with and without a cover should be suitably interspersed over the time available, rather than making all the early hauls without a cover and all the later ones with a cover or vice versa. The simplest plan in this case would be to make fishing conditions on each day as uniform as possible (for example, by fishing on the same ground throughout a day, by keeping the rig of the gear the same throughout a day, etc.) and to make both covered and uncovered hauls each day. The fishing ground may be changed and variations in the rig introduced, if desired, from day to day. Even within each day conditions are unlikely to remain exactly uniform, and in order to avoid any bias in each day's comparisons the order of making the covered and uncovered hauls should be determined by a random selection process. In this way, the order of making the hauls will be determined at the outset of the experiment strictly in accordance with the rules of chance and not in any other way, such as, for instance, on the basis of results so

far obtained. For details of the principle of randomization see Fisher (1949), Cox (1958) and Pope (1963).

One of the functions of randomization is to afford protection against any disturbances which may occur and which may or may not be serious if they do occur. Randomisation also provides a basis on which strict statistical tests of significance of experimental differences may be carried out.

In some experimental situations definite trends in experimental conditions may seem likely. Thus, in the course of a day's fishing it may be expected that there will be a trend in abundance of fish or in species composition due, for example, to daily migrations away from or on to the ground, or a trend in vulnerability due, for example, to changes in light intensity in the water. Either of these conditions may be thought likely to influence the experimental results in a way which, if not taken into account, might invalidate the conclusions drawn. It would then seem more reasonable to distribute the hauls with the different gears more evenly over the period than might be the case if the order was randomized in an unrestricted way, so that there is no chance that all hauls of one type are taken at the same time each day. Systemisation of order can be introduced while still retaining the necessary randomization to ensure validity of the statistical appraisal of the results. This may be done by employing an experimental design based on the Latin Square, which provides for each gear being used at a different time each day but, over the experimental period, is used at all times of the day. The method of randomizing the order of hauls subject to this type of restriction is to be found in, for example, Fisher and Yates (1963).

The Latin Square design requires that the number of days be an exact multiple of the number of different gears or cod-end and cover combinations, etc., used in the experiment. This usually raises no difficulty but, should there be more gears, etc., than days, alternative designs are available.

It is always advisable to take the trouble to randomise even when it is not expected that there will be any serious bias arising from failure to do so. But it cannot be stressed too strongly that it will generally be better to measure the effect of one variable with sureness and accuracy than to attempt to measure simultaneously the effects of several variables (e.g., in a cod-end, mesh size, material and catch size), and run the very real risk of obtaining unconvincing or inadequate results for them all. Thus in selectivity measurement it will usually be advisable to measure the effect of only one controllable variable, compare this with a standard, and obtain an acceptable result for this before measuring the effect of another controllable variable.

3.1.5 Comparison with standard. It is useful when measuring the selectivity of any one specific gear to simultaneously measure that of a standard gear. This serves to indicate, from variations in the apparent selectivity of the standard, the range of experimental error involved in the measurement and also, by an accumulation of results with the standard, provides a firm reference for estimating selectivity differentials between types of gear. ICES in 1970 adopted an exactly specified twine as standard for cod-end mesh selection comparisons (ICES Coop.Res.Rep. 25, 1971).

3.1.6 Escapes of fish from gear. In trawls and Danish seines there is an opportunity for fish to escape through the meshes of the net in front of the cod-end and some fish do escape there. It is common practice for the netting mesh size in these gears to decrease from the front of the net to the cod-end which is of the smallest mesh size in the whole net. However, experience and experiments (Margetts, 1963; Ellis, 1963) have shown that, provided the net does not taper sharply, very few individuals of many species which could escape through the big forward meshes do, in fact, do so but are channelled down into the cod-end, where the size selection by meshes is of critical importance. Fish found to escape from trawls forward of the cod-end have mostly been of certain species (e.g. sprats and Norway pout) and are very small indeed compared with the mesh sizes.

3.1.7 The gear in action. In considering both the design of a selectivity experiment and the interpretation of results, it is helpful to know how the gear works and its configuration in action. In early conservation experiments numerous trawl modifications were designed and made to ensure that cod-end meshes were held open. These were commonly known as "savings gears". None of them proved useful, because the design concept that meshes in a trawl are pulled shut when the trawl is towed was false. Davis (1934) demonstrated that cod-end size selection of fish took place while the trawl was fishing, and underwater films (United Kingdom, Ministry of Agriculture, Fisheries and Food, and Department of Agriculture and Fisheries for Scotland) have since shown that cod-end meshes are open while being towed. On some occasions fish have been seen to swim inside a trawl cod-end, heading in the direction of two and keeping station with a part of the cod-end. This, together with the experience of divers being partially carried along behind a trawl by the turbulent vortices set up, indicates that water is not funnelled down into the cod-end to rush out through the meshes but that the flow through the cod-end is perhaps not so great as through other parts of the trawl. If the cod-end meshes are markedly smaller than those in the forward netting, it is to be expected that total flow through the cod-end will be relatively small. So, although cod-end meshes are held open by the pull of the net against the water and the flow of water through them, the load in the twines forming those meshes is, for an empty or almost empty cod-end, likely to be in the order of 1-2 kg. Visual and photographic observations indicate that most escapes through cod-end meshes occur at the distal end and that as the catch accumulates at that end this becomes distended; escapes then occur mostly just in front of the accumulated catch. The effect of the filling of the cod-end is to somewhat widen the mesh openings where the catch accumulates and to narrow the openings in the forward part of the cod-end (Figure 3).

3.2 <u>The Covered Cod-end Method</u>

3.2.1 Principle

This involves attaching a cover of small-meshed netting over the cod-end in such a way as to retain fish which escape from the cod-end itself. A cover may envelop the whole cod-end or may cover only a part of it. The length distributions of the fish retained in the cod-end and those passing into the cover are then compared for each species.

3.2.2 Design and Rig of Covers

For the covered cod-end method to give a true measure of selectivity it is essential that the cover in no way affects the relative ability of fish of different sizes to escape from the cod-end. This method has frequently been criticized on the grounds that some fish which would normally escape from the cod-end if it were uncovered are prevented from doing so or are deterred by the presence of the cover. This effect is referred to as "masking".

Figure 4 shows the length frequency distributions (expressed as numbers per haul, in Figure 4a, and as percentages in Figure 4b) of catches of whiting (<u>Merlangius merlangius</u>) taken in the same cod-end in two sets of hauls made during the same period and on the same ground. In one set of hauls (8 in number) the cod-end was uncovered; in the other set (14 in number) the top half of the cod-end was covered by loosely fitting small mesh cotton netting in the manner shown in Figure 7. Clearly, from Figure 4a, the numbers taken per haul in the cod-end which was covered were, with one exception, greater at all sizes than the numbers taken with the uncovered cod-end. There was thus a general masking effect but it was greater for the smaller than for the larger fish. This is brought out in Figure 4b which shows that the percentage of fish of size less than 30 cm was consistently greater in the covered cod-end than in the uncovered one. However, although there is evidence of masking in these data, masking has not always been found in such experiments. Provided that in designing the cover, adequate care is taken to reduce masking to a minimum, unbiased estimates of selectivity can be obtained from the covered cod-end method.

Masking may be caused either directly by the cover lying against the cod-end, or the fish may perceive the cover, even if it is not lying against the cod-end, and be deterred from attempting to escape. Again, the presence of some fish in the space between the cover and

the cod-end may affect the escape of others. The flow of water through the cod-end may be altered when a cover is fitted and this too may reduce escapes.

The direction in which attempts have been made to improve cover design and rigging has therefore been toward ensuring adequate space between the cod-end and cover, in order thereby to reduce impedance to fish trying to escape and at the same time possibly not affecting water flow through the cod-end.

Cassie (1955) devised a method of suspending the cover in front of the cod-end from the belly and batings of the trawl net by means of rope toggles, so as to prevent it from lying against the cod-end during towing. Experiments carried out with a hemp cover of 63.5 mm ($2\frac{1}{2}$ inches) mesh size suspended in this way showed improvement of escape possibilities over earlier experiments with a cotton cover of mesh size 13 mm ($\frac{1}{2}$ inch) laced directly on to the forward end of the cod-end.

Beverton (1958) found that escapes of cod (Gadus morhua) from sisal and manila cod-ends were greater when using a cover with an extension bag than when using a similar cover with no extension bag.

Davis (1934), in his experiments, used cane hoops to keep the cover well clear of the cod-end. In spite of this precaution, however, he found strong evidence of masking in some of his hauls. Boerema (1958), on the other hand, reported increased selection when hoops were used to support the cover as illustrated in Figure 5. The cover had a mesh size of 30 mm and enveloped the whole cod-end, whereas that used by Davis probably had a mesh size of 10 mm and covered only the topside of the cod-end, the underside being blinded inside. Although the shooting and hauling from a small vessel of a small trawl fitted with hoops is not likely to present great difficulty, the same is probably not true with large trawls used on large ships.

In a study of the effect on selection of covers made from cotton and polyethylene, Pope (unpubl.) found that with the same cod-end the percentages of haddock escaping were higher when the polyethylene cover was used than when the cotton cover was used. Masking thus occurs to a lesser degree, if at all, when a cover of naturally buoyant material is used.

The advantages of using a cover which envelops the whole cod-end, as against one which covers only the topside, depends on whether fish escape through the underside or not, and this, in turn, is likely to depend on the construction of the gear and on the species being fished. Cieglewicz and Strzyzewski (1958) measured the number of escapes from the upper and lower halves of cod-ends of cotton, manila and rami from hauls made in the Baltic with the cod-ends covered by a whole cover divided into two compartments by horizontal sheets of netting. They found that more than 80 percent of the cod which escaped did so through the upper halves in the cod-ends made of cotton and manila, but that less than 30 percent of escapes were through the upper half of the rami cod-end. This difference they attributed to the lightness of the rami cod-end in comparison with the cotton and manila. This was borne out by the fact that when heavy chain was fixed to the lower side of the rami cod-end the percentage of escapes from the upper side rose to 44 percent. A wide range of values for the percentage escaping from the upper and lower sides of cod-ends has been reported by other workers.

Experiments made by the Marine Laboratory, Aberdeen, using cod-ends with topside covers and fitted with either underside chafers on the outside or small mesh blinders inside, have generally, though not always, shown that the percentage escapes are higher when a whole cover is used than when the top half only of the cod-end is covered.

Thus the following factors should be taken into consideration in devising a cover:

(a) the mesh size of the cover should be considerably smaller than that of the cod-end, so that the selection curves of the two sizes of mesh do not overlap;

(b) the cover should be rigged so that, when fishing, it can lie away from the cod-end;

(c) there should be ample space, at the after-end of the cover, to allow fish which have escaped from the cod-end to congregate without impeding further escapes;

(d) the normal flow of water through the cod-end should be interfered with as little as possible;

(e) wherever possible, a whole cover should be used in preference to one which covers only the topside of the cod-end;

(f) if only a topside cover is used, the underside of the cod-end should be lined on the inside ("blinded") with small-mesh netting.

As regards (a), when deciding on the cover mesh size, consideration must be given to making the cover netting strong enough to hold the likely catches in the fishery in which it is to be used. Because of (d) it should be no smaller than is necessary to ensure that fish of the smallest size occasionally retained in the cod-end cannot escape through the cover. In practice, it has been found that this requires the mesh size of the cover to be no less than half that of the cod-end. Bohl, Botha and Van Eck (1971) illustrate the effects of a cover with meshes too big.

To achieve (b) the cover should be very loose-fitting and, if practicable, be used with hoops or attached in such a way that the cover and cod-end netting remain apart while the trawl is fishing. Some cod-ends are made with a tapered front part leading to the main parallel-sided part of the cod-end; attachment of the cover at the widest part of the cod-end will then help to keep the cover netting away from the cod-end netting. A toggle arrangement can be useful for attaching the front end of the cover to the trawl belly or tapered fore part of the cod-end. The material of the cover should be as light as possible while being as strong as necessary to avoid bursting when heavy catches of small fish are taken. The use of naturally bouyant materials such as polyethylene or polypropylene for the cover is recommended.

With regard to (c), the cover should extend some way beyond the cod-end. Generally, experience suggests that this extension should be not less than 1.2 m and preferably 2 m, but the exact amount will be conditioned by the ability to get the cover, with its catch, aboard the vessel.

With regard to (d), the cover effect can be minimized by choosing the material, commensurate with the necessary mesh size and strength, such that the ratio of the diameter of the twine of the mesh slides to the area of lumen of the mesh is kept as low as possible and below that of the cod-end netting. Thus the material should be of as low a specific gravity, as high a tensile strength and as fine as possible.

With regard to (e), it may not always be sound practice to use a whole cover. On rough ground the underside of a whole cover will be liable to damage. This can be partly, but not always completely, avoided by fitting underside chafers, but the robustness of such chafers will be largely limited by the strength of the cover netting.

As regards (f), "blinding" of the underside of the cod-end will, of course, reduce the effective escape of the cod-end, but it does ensure that all escaping fish enter the cover. In reducing the effective escape area the possibility of a downward bias on selection cannot be ruled out. On the other hand, if no underside blinder is fitted, escapes may occur through the underside and the amount of these may vary even under relatively uniform conditions, thereby introducing a completely indeterminable factor.

Generally, a trawl cod-end is constructed with cod-line meshes different from the cod-end meshes. It is important that, when the cod-end is closed by tying the cod-line, no openings are left there bigger than the meshes of the cod-end.

To avoid loss of fish from the cod-end when the trawl is hauled, the fitting of some sort of one-way valve where the cod-end is joined to the belly of the net, e.g., floppa and pockets, is strongly recommended. Loss of fish at the end of a tow will introduce a bias to the results.

Figures 5, 6 and 7 illustrate useful cover designs.

3.2.3 Design of Experiment

The great advantages of the covered cod-end technique for measuring cod-end selectivity are that a length selection curve can be obtained from a single haul by one ship, and that the method quickly shows approximately at what lengths mesh selection occurs. However, single hauls are normally subject to quite large variability, so that it will usually be necessary to make several hauls to obtain a reasonably accurate estimate of the characteristic length selection curve. The accuracy of the selection curves from each tow will depend very much on the number of fish available in the selection range - the more fish, the better will be the data. But, on any one fishing ground, improvement in the accuracy of estimation of a length selection curve can only be gained by increasing the number of hauls. For this reason it is advisable to make as many hauls as possible during the experimental period. Although it is advisable in early stages of experimentation to tow for the same length of time as is done in relevant commercial practice, tows of shorter duration may with considerable advantage be used, provided that this does not affect the results in any way (see Section 5.1.4).

Included in any covered cod-end mesh selection experiment should be one or two hauls with the cod-end uncovered, to check that the cover is not appreciably masking the cod-end meshes; comparison of cod-end catches with and without the cover will then reveal any masking effect. Also to be included are hauls with another cod-end of the same mesh size but made of a specified standard material, if this has been decided upon (see Section 3.1.5). When hauls with different cod-ends are to be made, it is important that they should be spaced out in the experiment, so that bias and spurious effects are not introduced into the results. If only a few of these different hauls are to be made, then their timing must be chosen to be typical of the general fishing conditions, but if many of these hauls are to be made or if the need is to determine the effects of factors other than just mesh size on selection then it is most important that the order of hauls within the experimental period be randomized. If there are just two cod-ends under test, then a labour-saving compromise can be introduced by pairing the hauls, so that the cod-end has to be changed only once every two hauls.

As size selection by cod-end meshes is a function of the girth of the fish and as the mean girth for any length of any one species of roundfish often varies according to the season of the year, it is advisable that, if possible, a mean experiment aimed at deriving a mean selection factor should be repeated at different seasons of the year.

3.2.4 Practical Technique

In any covered cod-end experiment the first essential is to meticulously check the gear to ensure that the cod-end itself is perfect and has no broken meshes, that the cod-line is closed correctly with no oversize openings near it, that the cover is correctly rigged to operate properly without masking the cod-end, that there is no damage to the cover or the lower-side blinder (if used), and that the overhang of the cover is of the right length to take the anticipated catches without masking the cod-end and yet be brought on board the trawler conveniently.

If the experimental design requires frequent changes of cod-end this may be considerably speeded up by using a row of plastic rings on both cod-end and net and lacing these rows of rings together. This method is very frequently used in experimental work and on occasions by some commercial fishermen; it has been described by von Brandt, Kreuser and Messtorff (1958).

If new unused cod-ends are to be used, they should first be thoroughly stretched by use of a winch or windlass in order to tighten the knots and then, if they are of a material or twine construction which is subject to length change with wetting, they should be thoroughly soaked in water so that at least most of the initial shrinkage will have occurred before the covered net experiment begins. Even so, it is advisable also to make a haul or two with new cod-ends before the experiment proper is begun.

The actual fishing in the experiment should be done in a manner as nearly as possible the same as in the commercial fishery to which the selection results are to be applied; in particular, such variables as speed of tow and duration of tow should be about the same as are employed commercially.

When the gear is hauled and the catch is brought inboard it is most important that the two parts of the catch, that in the cod-end and that in the cover, should be kept separate. It will almost always be best to release the cover first. The cover catch can often be discharged from the cover directly into portable containers such as boxes or baskets. If baskets are used, they should be close-woven so as to retain small fish. The entire cover catch should be put into containers identified by (for example) labels and removed well away from where the cod-end catch is to be discharged. When the cod-end has been released it too should be put into containers. Fish meshed in the cod-end should be removed and included in the cod-end catch. Fish washed in the trawl forward of the cod-end should be removed and discarded.

After every haul the cod-end mesh should be measured (see Section 3.5). At the time the cod-end and cover should be carefully examined and any damage recorded and repaired. If damage or unusual happenings such as the inclusion in the catch of large quantities of weed or rocks are likely to have affected the selection process, then this should be recorded and a decision about the validity of the haul made there and then. Hauls rendered invalid through damage to the gear during fishing should be rejected.

The fish should then be sorted by species and measured, keeping cover and cod-end catches carefully separate (see Section 3.6). If space aboard the experimental vessel permits two measuring teams to work simultaneously, this is probably best done by arranging for one team to deal with only the cod-end catch and the other with only the cover catch. Otherwise, one of the catches should be dealt with completely before proceeding to deal with the other. The length measurements of the two catches should subsequently be summarized on a suitably arranged working sheet such as that shown in Table I. A separate sheet should be used for each species from which selection data are obtainable.

Besides noting fish lengths it is also advisable to record the numbers of all species taken and the weights of the total cod-end and cover catches separately. The size of the catch may have an effect on the length selection pattern (see Section 5.1.4).

Haul by haul throughout the experiment all relevant information should be noted in detail. Section 6 lists many of the items of relevant information.

3.2.5 Initial Processing of Data

In order to keep effective control over the experiment it is useful to make as soon as possible a rough plot of the percentages retained. This is done, first of all for each haul, by adding together the number of fish in cod-end and in cover at each unit of length and then expressing the number in the cod-end as a percentage of the total number of fish at each length. The data given in Table I relate to an actual set of observations for haddock (*Melanogrammus aeglefinus*) taken in a haul of one hour's duration. In column (1) is given a length scale with a suitably chosen grouping interval, one centimetre in this case. Columns (2) and (3) show the number of fish in each interval taken in the cod-end and cover respectively. The fourth column shows the number of fish in each interval taken in the cod-end and cover added together, and the fifth column shows the percentages retained in each interval. The percentages need only be given to the nearest whole number and may easily be

found with the aid of a slide-rule or a desk calculating machine. The figures in column (5) are shown plotted in Figure 1. Besides the haul-by-haul check, it is useful to pool together all the data from similar types of hauls and calculate the percentages retained. For this, all the cover catches at each unit of length are added and similarly all the cod-end catches are added. The two columns of figures are then treated as above. When the percentage retained is plotted against length a smooth selection curve can be drawn to the points by eye. The obviousness of the selection curve gives a good indication as to the quality of results being obtained.

3.3 The Alternate Haul Method

3.3.1 Principle

By this method, which applies to trawls and Danish seines, the selection curve is estimated from hauls in which the cod-end is uncovered (i.e., fished naturally). The length distribution of the fish over the total or major part of the selection range in the area where fishing takes place may be obtained by estimating the size distribution of the fish on the grounds from hauls using a cod-end of much smaller mesh size than that of the cod-end whose length selection curve is to be determined. (In practice, it is sufficient that the cod-end of smaller mesh size selects fish only below the selection range of the experimental cod-end.) A direct comparison of this size distribution with that of the catches by the experimental cod-end then provides estimates of the percentage retention at each length by the experimental cod-end.

The most straightforward method and the one most free from experimental complications is that in which both the experimental cod-end and the standard (smaller-meshed) cod-end are used with the same gear fished from the same ship. In the early applications of this method the cod-ends were used alternatively and this gave rise to the name "alternate haul method" for this technique. The term is, however, generally used to cover not only that particular type of experimental method but also that in which the order of use of the cod-ends is randomized over the period, as distinct from that in which the cod-ends are used alternately or in which the cod-ends are used on different vessels fishing at the same time over the same ground. In the latter situation any difference in the fishing powers of the two vessels must be capable of evaluation.

3.3.2 Design of Experiment

This method is essentially one requiring sustained comparative fishing, because of the spacing in time of the hauls to be compared. Whether the hauls are truly alternate or in alternate pairs to economise on gear changes, it is imperative that they be so arranged during the period of experiment that the same number of valid hauls is made with each cod-end and that, in total, each gear has been used equally throughout the time period.

3.3.3 Practical Technique

The haul-by-haul procedure is much the same as for the covered cod-end method (see Section 3.2.4). Knot tightening and initial shrinkage should be completed before the experiment is begun and the gear checked over before and after every haul. One thing that can cause trouble is the introduction of too abrupt a mesh change in the trawl when the small-meshed cod-end is fitted. It is not enough to simply substitute one cod-end for another which is the same except for mesh size; mesh size must as far as is possible be changed gradually along the length of a trawl if it is to fish satisfactorily, so the small-meshed cod-end must be fitted with a suitable tapering front end incorporating a graduation of mesh sizes to avoid a sharp constriction of the net when it is attached to the trawl.

After each haul (which should all be of the same duration and that similar to commercial practice, and for which all relevant details should be recorded) the fish are sorted and measured, record being kept of the quantities of each species caught. Hauls which for any reason are considered invalid should be rejected and, where necessary to maintain the statistical balance or coverage in the experiment, should be repeated.

3.3.4 Initial Processing of Data

For each cod-end its catches on each haul are summed at each unit of length. Then, at each length, the catch in the cod-end under investigation is expressed as a percentage of the catch in the small-meshed cod-end. An example of deriving a length selection curve from alternate haul data is given in Table II. Column A gives the length frequency distribution of haddock taken in two one-hour hauls by a trawl with a cod-end of average mesh 35 mm. Column B gives the length frequency distribution for two one-hour hauls with a polypropylene cod-end of average mesh size 87 mm. These frequency distributions are shown graphically in Figure 8.

Taking the figures in column A as representing the length frequency distribution of fish on the ground, at least over the selection range of the polypropylene cod-end, the ratios B/A shown in column C will give the proportion at each length which escape through the polypropylene cod-end, i.e., the cod-end with the larger mesh. It will be observed, however, that from 31 cm upward the larger-meshed cod-end caught more fish than the smaller-meshed cod-end. In part, this will be due to sampling variation, but even when very large numbers of hauls are involved this feature is quite common in alternate haul experiments and it has been suggested that it may be due also to an increase in the fishing power of the gear arising from an increase in cod-end mesh size (Davis, 1934; Beverton and Holt, 1957).

Assuming here that proportionately more fish were taken at all sizes by the polypropylene cod-end, the necessary adjustment to the ratios B/A may be made by dividing by a factor expressing the catching efficiency of this cod-end relative to the cod-end with the smaller mesh. This factor may be estimated from the ratio of the catches above the selection range, in this case above 31 cm. The average of the ratios from 32 cm to 39 cm inclusive is 1.28, and the ratios of column C adjusted by dividing by 1.28 are shown in column D. The ratios above 39 cm have, in this case, been ignored since the numbers of fish taken above 39 cm are small and the ratios are very variable and quite different from those in the range 32-39 cm. An alternative way of making the adjustment is to use the ratio of the total numbers caught above the selection range, this being 682/531 = 1.28, which gives the same adjustment in this case. The adjusted ratios of column D are shown plotted in Figure 8b. A curve drawn freehand through the points gives an estimated 50 percent point of 30 cm. This adjustment, in effect, involves equalising the catches of the two cod-ends above the selection range, and the adjustment factor may sometimes conveniently be estimated by first plotting the ratios B/A in column C and reading off the level at which the selection ogive flattens at the top; the difference between this percentage and 100 percent represents the adjustment factor. For a fuller account of the method, see Beverton and Holt (1957).

3.4 <u>Variants of the Alternate Haul Method</u>

3.4.1 Closely Similar Meshes

Instead of alternating between the cod-end under test and a small-meshed cod-end, two cod-ends of closely similar mesh size may be used. In this case their selection curves overlap. The design of the experiment and the practical technique are as in Section 3.3. Beverton and Holt (1957) describe a method of estimating the 50 percent selection points of two such similar cod-ends which requires the reasonable assumption that the selection curves of both cod-ends are normal ogives with the same standard deviation. In this method the selection curve of the cod-end under test is calculated from comparison of the two length distributions and is then adjusted to allow for the fact that the smaller-meshed cod-end was itself selecting in the selection range of the test cod-end. The adjustment is done by matching the first calculated selection curve to theoretical ogive ratio curves which are plotted as ratios of ordinates of pairs of normal curves having the same standard deviation but with means displaced by various amounts.

3.4.2 Parallel Fishing

Thsi involves two ships fishing on the same ground at the same time, the only difference between their gears being the mesh size. By so doing, some of the effects of the many

uncontrolled variables inherent in the true alternate haul method are eliminated or greatly reduced. Thus, although the experimental effort and expenditure per day in parallel fishing will be about double that on an alternate haul experiment, the total duration of the parallel fishing experiment will need to be considerably less than half of that of the alternate haul experiment while achieving the same accuracy. Parallel fishing is here taken to mean either two ships fishing side by side, shooting, towing and hauling simultaneously, or two ships fishing the same ground over the same extended period of time, as described by Davis (1934). The former, true parallel fishing, is less liable to error and thus requires fewer hauls to achieve any particular level of accuracy. In parallel fishing it is essential that the gears should be exchanged between the ships at regular and fairly frequent intervals, the frequency depending on the exact form and duration of the experiment.

3.4.3 "Trouser Trawl"

This method involves only a single ship using a single trawl, but that trawl is fitted with two cod-ends side by side. The two cod-ends are of different mesh sizes; they can be very different, as referred to in the "alternate haul method" described in Section 3.3, or only slightly different as in Section 3.4.1. The method is theoretically very attractive, especially as selectivity data for one or both cod-ends can be obtained from single hauls and uncontrolled experimental variables can be kept to a minimum. But, in practice, difficulties have usually arisen through the catches of fish above the selection range of the bigger-meshed cod-end being very unequal in the two legs of the trawl. This, which might in some way be due to differences in water flow through the two cod-ends consequent upon the different mesh sizes, has however occurred in experiments where the mesh sizes are closely similar. Uneven fishing of the two cod-ends could be caused by effects of wind and tide displacing the trawl from being towed squarely, but, whatever its cause, this feature of trouser trawl fishing complicates the measurement of mesh selection.

3.5 Comparison of Methods

Choice of method will generally be governed by the type of gear under test and the facilities available. But for trawls and Danish seines the choice between covered cod-end and alternate haul methods may be more open.

The attractiveness of the covered cod-end method lies in the fact that results are obtainable from single hauls and the actual escapes are observed. In practice, the method is a relatively easy one and the analysis of the results is straightforward. Each haul is in itself a complete experiment, and repeated hauls are needed only to improve the data and reduce the magnitude of sampling errors. Furthermore, covered cod-end results are independent of the catching efficiency of the trawl and are less affected by variations in the size composition of the fish population sampled than are the alternate haul results. The covered cod-end method is the only one, apart from underwater observations, which shows beyond doubt that fish have actually escaped through the cod-end rather than from other parts of the trawl, and it gives absolute rather than comparative estimates of escapes for each mesh size.

The special merit of the alternate haul method is that it is free from any bias caused by the use of a cover. There are, however, several disadvantages in the method. Because of haul-to-haul variation in catches, a much larger number of hauls are usually required to achieve the same precision of estimation as is given by the covered cod-end technique. A serious technical complication can be the change (usually an increase) in catching capacity of a net with increase in cod-end mesh size.

It is a common feature of the alternate haul method that it gives higher estimates of 50 percent points than the covered cod-end method. In view of the fact that the alternate haul method is a direct experimental parallel of what would happen in a commercial fishery when cod-end mesh sizes are changed, it is likely that estimated 50 percent points obtained by this method may be nearer the required figure than those given by the covered method, provided that an adequate number of hauls is

Points in favour of the alternate haul method are that the work can be conducted from a commercial fishing vessel or vessels with the minimum of interference with normal working, and that it gives the only practical estimate of what immediate gain or loss is likely to result from a change in mesh size in a fishery; it is the best, if not the only, means of estimating any increase in catch of bigger fish by a bigger mesh size.

When the choice falls on an alternate haul method, it can be useful to do a preliminary haul or hauls with a covered cod-end to gain an idea as to the selection range of the cod-end for the particular species. If the range is very long, as for example it is for trawl-caught *Nephrops* in a trawl cod-end, then the variant of alternate hauls described in Section 3.4.1 may be preferable to the method employing a small-meshed cod-end for comparison, because the selection range of the cod-end under test could overlap with that of the small-meshed cod-end.

When trawling must be done on rough or hazardous grounds, the alternate haul method is at a disadvantage compared with the covered cod-end method, because a total loss of the cod-end is more likely in the longer fishing period necessary, and such a loss can be more damaging to the experiment because it breaks up a series of hauls with consequent loss of accuracy.

3.6 Gillnets

3.6.1 Design of Experiment

Gillnets of one or more mesh size are fished, all in a similar fashion. Depending on the method of estimating selectivity, (a) the catch in each mesh size is compared either with the catches in other mesh sizes or with the size distribution of the fish population; or (b) changes in the catch per effort are observed.

When different mesh sizes are used, they must fish in a comparable manner. Usually nets of all mesh sizes are placed end-to-end in a long gang; this is convenient but may not give the best results, because all positions in a gang may not be equivalent and because the nets may affect the catch of each other. For example, in small bodies of water the nets near shore may be exposed to a different fish population than the nets further out. Within a gang, the catch of one net may be reduced by that of an adjacent, more efficient net (Larkins, 1963); or large fish may lead along a small-meshed net until they come to, and are captured by, a larger-meshed net. All these problems can be avoided by fishing each mesh size in its own gang, with the gangs set far enough apart that they do not compete for capture of the same fish. When different mesh sizes must for practical reasons be set in the same gang, their order should be chosen at random and changed each time the gang is set; and gaps left between the nets to alleviate the problem of leading.

Because different-sized fish may occupy different habitats, the locations of setting nets should be distributed randomly over the whole area of fishing. Once the locations are chosen, the mesh sizes should be apportioned to them, each day, either at random or according to a Latin Square design. Nets should be set and lifted consistently at the same times of day. They should be lifted daily; in any case they should not be left in water for so long that their efficiency is reduced by saturation (accumulation of captured fish) or by fouling with algae or silt.

In addition to mesh size, other characteristics of nets can affect selectivity and efficiency, and must be standardised. In particular, net dimensions and hanging coefficient, and twine material, thickness and colour must be the same for all nets. This information should be recorded in the published report to allow comparison with other studies.

For quick recognition of the different mesh sizes, the nets can be colour coded, for example by splicing a piece of coloured twine near each end of the floatline.

3.6.2 Collection of Catch Data

The minimum data to be collected are, separately for each mesh size, the numbers of nets set and the numbers of fish caught in each size class. These should be recorded separately for each day, to allow detection of trends.

Girth measurements contain much useful information and, if possible, all length classes of fish should be sampled for:

(a) Head girth at rear edge of operculum - this determines the smallest mesh into which the fish can penetrate far enough to be gilled or wedged by body.

(b) Maximum girth - this determines the largest mesh which can hold the fish wedged; it is affected by the nutritional condition and sexual ripeness of the fish and therefore is more variable than head girth.

(c) Girth at netmark - this gives a measure of how much the mesh has stretched and the fish body compressed.

Hunter and Wheeler (1972) described a device which allows quick and easy measurement of girths as well as lengths.

Another type of information which can be very useful but is time-consuming to collect is how each fish was caught in the net. Such records allow estimating multimodal or otherwise complex selectivity curves as the sums of simpler component curves (see Section 4.6.5). Making the observations is difficult because the fish may become stuck in several meshes by the time the net is lifted; but usually the meshes of secondary capture remain on top of the original one, and a careful unravelling of the net reveals the original way of capture. In some cases it may not be possible to decide between two or three ways of capture; then they all should be recorded.

3.7 Hooks

What has been said under 3.6.1 for gillnets also applies in principle to hooks, because the same methods are used to estimate the selectivity of both.

Each unit of groundline (skate, basket, etc.) should contain only a single size of hooks. With several sizes of hooks on the same line there is too much chance of error in recording catch data; also, the captures by one size of hooks may be reduced by adjacent, more efficient hooks. A unit of groundline containing a single size of hooks is analogous to a gillnet of a single mesh size, and same considerations of experimental design apply to both.

The selectivity of a hook depends mainly on its gape (Figure 9), but other characteristics of the hooks, baits and lines may also be important and must be standardised. Of particular importance may be the shape and colour of the hook, the gauge of metal it is made from, the kind and size of bait, and the interval between hooks on the groundline; this information should be recorded in the published report to allow comparison with other studies.

The data to be collected are, separately for each hook size, the number of hooks set and the numbers of fish caught in each size class. These should be recorded separately for each day. Little is known about the dimensions of fish that are critical to hook selectivity (such as girth is to mesh selectivity); possibly the gape of the mouth relates to the minimum size of fish caught.

3.8

The size of mesh used is one of the most important parameters to be measured in any mesh selection experiment, yet too often it has been inadequately measured either because of poor sampling (frequency of measurement and number of meshes) or because of poor technique (inaccurate and non-standard gauge). For a trawl cod-end experiment with roundfish such as haddock, when a mesh size of about 90 mm is being used, a variation of only 3 mm in the recorded mesh size represents a variation of about 0.1 in the calculated selection factor. Yet variations of more than 3 mm in mesh size measurement occur commonly between different methods of measuring the mean mesh size in one cod-end.

It is to be expected that escapes of fish through a cod-end will be related to the size of its meshes as they configurate under fishing conditions, but this is something which cannot be measured directly. Hence mesh size is measured according to an arbitrary standard. The International Standards Organisation (ISO) defines size of mesh in the following way:

- length of mesh side - the distance betwenn two sequential knots or joints, measured from centre to centre when the yarn between those points is fully extended;

- length of mesh - for knotted netting, the distance between the centres of two opposite knots in the same mesh when fully extended in the N-direction (i.e., the direction at right angles to the general course of the netting yarn), and, for knotless netting, the distance between the centres of two opposite joints in the same mesh when fully extended along its longest possible axis;

- opening of mesh - for knotted netting, the inside distance between two opposite knots in the same mesh when fully extended in the N-direction, and, for knotless netting, the inside distance between two opposite joints in the same mesh when fully extended along its longest possible axis.

Thus the length of mesh side (sometimes called bar length) is half the stretched length of mesh measured to include a knot at one end, and the opening of mesh is directly related to the perimeter of the mesh lumen. The useful measure of mesh size in selectivity experiments is therefore the opening of the mesh. This dimension can be (and has been, in many different mesh experiments) measured in a variety of ways. The measurement recorded for it is very much dependant upon the loading put on to the mesh to extend it; consequently, the loading and the type of gauge used must be specified, and as far as possible standardised, for comparative purposes.

Two major groups of mesh-measuring devices have been used. They are:

(a) flat, wedge-shaped pieces of metal of graduated width, which are pushed by hand into the meshes at right angles to the plan of opposite knots, and which may or may not be equipped with a means of measuring and controlling the pressure applied in inserting the gauge;

(b) gauges which exert a longitudinal force between opposite knots of the mesh, i.e., a force across the inside of the mesh in the plane of the netting; a wide variety of gauges of this type have been designed, all of them incorporating a means of controlling and/or standardizing the pressure exerted during measuring.

Several descriptions of mesh-measuring gauges are to be found in the literature and reference should be made to Parrish, Jones and Pope (1956), von Brandt and Bohl (1959), Bedford and Beverton (1955), and Westhoff, Pope and Beverton (1962).

The conclusion from experiments with different gauges is that greater accuracy and consistency of measurement is obtained with longitudinal pressure gauges than with wedge-shaped gauges, even when the latter are fitted with pressure controlling mechanisms. Gauges such as the flat wedge-shaped ones pushed into the mesh at right angles to the plane of the netting are not very useful for accurate measurement; if they have no pressure-regulating device at all, they are subject to very big operator errors. With this type of gauge, variations in measurements will occur not only with variation in the force with which the gauge is pushed into the mesh, but also with the degree of taper of the gauge, with the way the netting is hung up or laid out, and with the friction between the gauge and the netting.

The inclusion of a stopping device in longitudinal spring-loaded mesh gauges to that the load applied in obtaining the measurement cannot exceed a certain previously defined value, has been generally recommended and adopted. The International Council for the Exploration of the Sea (ICES) has recommended the use of the so-called ICES gauge (Westhoff, Pope and Beverton, 1962) for all scientific mesh measurement purposes (Figure 10).

Whilst a large measure of agreement has been reached on the correct pressure to apply in measuring the meshes of cod-ends of certain materials (namely, double manila, double hemp, double cotton, thick single manila), the pressure chosen has been arrived at mainly on the subjective grounds of requiring the bars of the meshes to be fully straightened but not stretched elastically nor so that the knots are tightened to a degree in excess of that which occurs in fishing. For the cod-end materials mentioned above the agreed pressure in European scientific work is 4 kg. Ideally, a gauge loading should depend upon the material of the meshes to be measured and the probable load on the mesh sides in action. For example, ISO recommends that in testing net materials for shrinkage, a useful load to suitably extend a twine is that equal to the weight of 250 m of the twine. Thus, for nets of finer twine than those mentioned above, a loading of considerably less than 4 kg will be appropriate.

It should be noted that even with a spring-loaded gauge, especially with double-braided meshes of thick twine, error can be introduced by the way in which the gauge is inserted into the mesh, because at one end of the mesh the gauge can lodge in one of three positions against the knot. Consistency in operation should be sought here by measuring with the gauge in the middle position of the three (see Figure 11).

If no gauge is available, a useful measure of mesh opening can be made by pulling the netting lengthwise (that is in the N-direction) so that the meshes are closed with their side knots touching and then measuring the distance between inside edges of opposite knots in the N-direction with a ruler.

For some nets, especially very small-meshed ones, measuring the opening of the mesh is scarcely practical. Then a method such as stretching out the netting and counting the number of rows of knots or of meshes per unit length may be more appropriate, but it should be noted that this is in effect measuring the length of mesh, and conversion to size of opening of mesh must take account of knot size.

In practice, the meshes of a cod-end will vary in size, due either to the unevenness of braiding, especially if this is done by hand, or to differential loadings being imposed over the cod-end when in use. When relating 50 percent retention lengths to mesh size, therefore, it is necessary to work with the average mesh size. The number of meshes to be measured in order to arrive at a sufficiently accurate estimate of the average mesh size will depend on the degree of variation in mesh size. For any given cod-end this can only be determined by measurement, although experience is likely to indicate that the degree of variation in cod-ends of the same material and braiding from the same source is sufficiently constant to enable, in time, the minimum number of meshes to be stated in advance. The accuracy of the mean mesh size can be evaluated in the usual way from its standard error.

Since the minimum number of meshes to be measured will normally be considerably less than the total number of meshes in the cod-end, the question naturally arises as to where in the cod-end the measurements should be taken. This should be in the area where the majority of escapes take place. Beverton (1963), von Brandt (1960), Clark (1957c) and Cieglewicz and Strzyzewski (1958) have found that most fish escape through the after part of the cod-end and therefore more meshes should be measured in this area than in the forward part if there is a trend in mesh size along the cod-end. As a routine the meshes measured should be located on the topside in a line running parallel to the long axis and starting from the after end of the cod-end some two or three meshes from the cod-line. Measurements should be recorded serially to enable any fore-aft trend to be detected. The line should not be located near the selvedges, and meshes near or adjacent to strengthening ropes and lacings should not be measured.

Cod-end measurements should be made immediately after every haul while the cod-end is still wet. The number of meshes to be measured should not be fixed arbitrarily, because the minimum number to be measured depends on the desired accuracy of the average and on the standard deviation of the mesh size, which will vary with cod-end construction and usage. It will usually be necessary that the mean mesh size be determined with an error of not more than 2 percent. To this end, if the observed 95 percent range of meshes is 20 mm and the

average is required to within 2 mm of the true value, measurement of about 25 meshes will usually be sufficient. If the number of meshes in one line is not sufficient a complete second line should be measured.

Because of obstruction by the cover, the mesh measurer may be faced with difficulties in getting to the meshes that he wants to measure in a covered cod-end. When an all-round cover is fitted it can be slid back from the cod-line to expose the topside of the cod-end. When only the topside of the cod-end is covered, it may be possible, if it is light enough, to turn the cod-end inside out, thus avoiding having to detach it, and so expose the topside from within; if the cod-end is heavy, the cover may be lifted to allow the measurer to walk or crawl from the cod-line up over the topside of the cod-end between cod-end and cover. (If there is not room enough for this, then the cover may have been rigged too tightly and the gear should be checked for this point.)

In quoting mesh sizes in scientific reports, the number of measurements and the standard error of the mean size should be included as well as the average mesh size and range.

3.9 Fish Measurement

The fish caught, segregated into separate lots according to which unit of gear, net, cod-end, cover, etc., they are from, should be measured for length after total quantities caught by each unit have been recorded. The type of length measurement made, e.g., whether overall length or fork length, should be noted on the length record form. It is most common nowadays for fish to be measured to the length interval below, but this and any departure from it should be stated on the record form. The choice of unit for the length group interval will depend upon the range of the fish length distribution, on the size of fish being selected and on the sharpness of selection. For many fish a one centimetre grouping is convenient. It should be remembered that when fish have been measured to the length interval below, adjustment must be made for this in plotting the selection curve by displacing it to the right by half a length interval.

In addition to recording the length measurements of the species whose length selection curve is being investigated, it is advisable, if time permits, to record also the lengths of all other species taken in the hauls. This may permit further analyses of the data that are not contemplated at the time the experiment is planned or carried out. When catches are very heavy there may be insufficient time for dealing with each species in full, and sampling may have to be introduced. Provided that sampling is undertaken with care there is no reason why unbiased estimates of length frequency distributions or other catch data should not be obtained. If the major species is taken in very large quantities over its entire size range, the simplest procedure is to take a uniform fraction of the fish over the whole range. If, on the other hand, large numbers are taken in the size ranges outside the selection range but not within it, it is better to confine the sampling to the sizes outside the selection range.

The most efficient sampling procedure will vary according to conditions and requirements, and so no scheme optimum under all circumstances can be stated. Ideally, strictly valid statistical sampling entails the random selection (in the probability sense) of fish, a requirement which can rarely be met under working conditions. However, something closely approximating to this can usually be attained with little difficulty. The accuracy of whatever form of sampling is used can generally be assessed by making one or two small-scale experiments. A manual of sampling methods for fisheries biology has been prepared by Gulland (1962), in which the methods of developing a good sampling system for the quantities of major interest in fisheries biological research are outlined in great detail.

When catches of fish are very large indeed, one useful way of sampling is first to decide what proportion of the catch would be a more manageable quantity and then, as the fish are put into unit containers, to set aside the proportion for further sampling and measuring. For example, if it was decided that one third of the catch would be enough, then, from the very start of putting the fish into containers every third container would be set aside and the rest rejected. Then, from the set-aside sample a further sub-sample might be taken after

a thorough "Dutch shuffle". When catches are not quite so large, but sampling is still desirable, it is often best to put all the fish in containers and "Dutch shuffle" before taking a proportion for measuring. The choice of what proportion of the catch should be taken as a sample should be made so that the raising factor of the sample to the total catch is a whole number.

It has already been pointed out in Section 2.1 that the dimension of a fish which determines whether it escapes or is held by a mesh is not directly its length but its maximum girth. Selection factors for a given mesh size and different populations of the same fish species may therefore vary if different girth/length relationships are exhibited by the different populations. Even within the same population there may be seasonal or longer-term changes in the girth/length relationship, associated with the stage of maturity, with variations in feeding rate, with different growth patterns in different year classes, etc. Stratified samples throughout the length distribution of the catches should be taken regularly for girth measurements.

In the case of roundfish, the girth may be measured at two points along the body, either at the point of maximum head girth, which occurs in the region of the pterotic bone, or at the point of maximum body girth, which is often near the position of the anal vent. The body girth may be conveniently measured with a tape measure noose as the constricted body girth after the manner of Margetts (1957), who gives body girth/length relationships for North Sea whiting and cod and a discussion on the application of such relationships to mesh selection. If necessary, the air bladder should be punctured prior to measuring body girth. Lucas *et al.* (1954) discuss the application of head girth/length relationships to mesh selection. The decision as to which is the best position on the fish for girth measurement will depend to some extent upon the type of gear under test, and to some extent upon the information sought; for example, for investigation of the effect of season of the year on trawl cod-end selectivity, it will be the position of maximum girth, wherever that is along the body.

4. PROCESSING DATA

In Section 3, for each type of experiment the general methods of working up the collected data to yield estimates of selectivity are briefly described. The present section is concerned especially with statistical methods of final processing and evaluation of the data. Many of the methods described are rather sophisticated and complicated; whether or not any particular statistical process should be employed will be indicated by a preliminary judgement of the quality of the raw data and by the particular aspect of selectivity that is sought, for example, whether most importance is to be attached to the selection factor, to the selection range, to the 100 percent point or to the 0 percent point. There is little value in adopting a complicated statistical technique if by using a simpler one the error in curve-fitting is still well within the experimental error of the basic data. It should also be noted that, particularly from covered cod-end experiments, the tail regions of selection curves often show very irregular fluctuations and sometimes, especially the lower one, are missing.

4.1 Methods of Fitting Selection Curves

4.1.1 By Eye

The simplest and at present most widely used method of fitting a selection curve is to draw, by eye, a smooth curve passing as closely as possible through the observed points. Although practice brings with it a certain amount of skill in exercising correct judgement, this method is subject to criticism on two counts. In the first place no two people are likely to draw exactly the same curve to a given set of points, nor even can the same person be sure of repeating the same curve in fitting twice to the same data. In the second place, no estimate of the error of fitting is available. Nevertheless, the method is quick and is the best for a preliminary analysis, and is often sufficient for the final purposes.

4.1.2 Linear Regression

This can be useful in finding the 50 percent point. The middle point of the selection curve, say between 25 percent and 75 percent retained lengths, is approximated to a straight line and this is fitted by the method of weighted or unweighted least squares.

4.1.3 Linear Regression by Deviates

Some simplification can be introduced into the fitting of the curve. If the true curve is assumed to have the sigmoid form of the normal ogive, then instead of plotting the proportion retained against length, the corresponding normal deviate may be plotted against length, whereby the relationship is linearised and the fitting reduces to that of drawing a straight line. Alternatively, Tables of Probits, which are normal deviates with 5 added, may be used. Suitable tables are to be found in "Statistical Tables for Biological, Agricultural and Medical Research" (Fisher and Yates, 1963, Table IX) and elsewhere. For example, using the selection data in Table I, we find, from Fisher and Yates' table, the entry 3.1192 for a value of P = 3, this being the percentage escaping at a length of 19 cm. The normal deviate is, therefore, −1.8808 which may be rounded to −1.88. The transformed data are:

Length (cm)	18	19	20	21	22	23	24	25	26	27
Percentage	0	3	6	20	30	55	80	89	92	100
Normal Deviate	− oo	−1.88	−1.55	−0.84	−0.52	0.13	0.84	1.23	1.41	+ oo

The normal deviates are shown plotted in Figure 12 with a straight line fitted by eye ignoring the points at ± oo. The 50 percent retention length read off the fitted line is 22.8 cm, this being the length corresponding to a normal deviate of zero. The 25 percent and 75 percent retention lengths correspond to normal deviates of −0.67 and +0.67 respectively, and, from the graph, give the values 21.5 cm and 24.1 cm. The selection range is, therefore, 2.6 cm. It is, of course, unnecessary to carry out the process of fitting and

estimation with normal deviates; the unadjusted probits may be employed equally well. These values may be compared with the following values which were obtained from Figure 1: 50 percent retention length = 22.9 cm; 25 percent, 75 percent retention lengths = 21.6 cm, 24.0 cm; selection range = 2.4 cm.

Special graph paper, called arithmetic probability paper, has been prepared, in which the ordinate scale is graduated in terms of normal deviates. This obviates the necessity for a table of normal deviates.

If the curve is assumed to follow the logistic law rather than the normal, the curve is similarly transformed into linear form by plotting quantities called logits, against length. Special graph paper, called logistic paper, may be used for this purpose or alternatively tables of logits such as are found in Fisher and Yates' Tables (Table XI).

No estimate of variance is available for a 50 percent retention length obtained by these graphical methods.

4.1.4 Moving Averages

Fifty percent points may be simply estimated by the method of moving averages. This method consists of calculating moving averages of the p's and l's and using linear interpolation in the resulting series to find the 50 percent point. Thus, if p_1, p_2 ..... are the proportions escaping at lengths l_1, l_2 ..... and if 3-point moving averages are used, a new series of $\bar{p}$'s and $\bar{l}$'s are obtained thus:

$$\bar{p}_2 = (p_1 + p_2 + p_3)/3 \qquad \bar{l}_2 = (l_1 + l_2 + l_3)/3$$

$$\bar{p}_3 = (p_2 + p_3 + p_4)/3 \qquad \bar{l}_3 = (l_2 + l_3 + l_4)/3$$

For the data of Table I we have:

$\bar{p}_2 = 0.03$	$\bar{l}_2 = 19$
$\bar{p}_3 = 0.10$	$\bar{l}_3 = 20$
$\bar{p}_4 = 0.19$	$\bar{l}_4 = 21$
$\bar{p}_5 = 0.35$	$\bar{l}_5 = 22$
$\bar{p}_6 = 0.55$	$\bar{l}_6 = 23$
$\bar{p}_7 = 0.75$	$\bar{l}_7 = 24$
$\bar{p}_8 = 0.87$	$\bar{l}_8 = 25$
$\bar{p}_9 = 0.94$	$\bar{l}_9 = 26$

The 50 percent point lies between $\bar{l}_5$ and $\bar{l}_6$ and is, by linear interpolation, equal to $22 + (0.50-0.35)/(0.55-0.35) = 22 + 0.75$ cm = 22.75 cm.

In applying the moving average method spans of length other than 3 units may be used. The use of spans of odd order is very convenient if the l-values are equally spaced, as will usually be the case, for then the values of $\bar{l}$ coincide with the original l's.

Although this method is suitable for estimating the 50 percent point of the length selection curve, it should not be used for estimating any other percentage point.

If it is assumed that the number of escapes of fish of a given length follows the binomial distribution, an expression for the variance of the estimated 50 percent point (var l_{50}) is available. When it is estimated by interpolating between the 3-point moving averages $\bar{p}_{i+1} < 0.50$ and $\bar{p}_{i+2} > 0.50$ it is given by

$$\text{var}\ (l_{50}) = \left\{ f^2\ \frac{p_i q_i}{n_i - 1} + \frac{p_{i+1}\ q_{i+1}}{n_{i+1} - 1} + \frac{p_{i+2}\ q_{i+2}}{n_{i+2} - 1} + (1-f)^2\ \frac{p_{i+3}\ q_{i+3}}{n_{i+3} - 1} \right\} \cdot \frac{d^2}{(p_i - p_{i+3})^2}$$

where p_i, p_{i+1}, ... are the observed proportions escaping at lengths l_i, l_{i+1}, ...; $q_i = 1 - p_i$, $q_{i+1} = 1 - p_{i+1}$, ...; n_i, n_{i+1}, ... are the total number of fish (cod-end plus cover) of lengths l_i, l_{i+1}, ...; d is the (common) length interval employed and

$$f = \frac{p_{i+1} + p_{i+2} + p_{i+3} - 1.50}{p_{i+3} - p_i}$$

This expression for var (l_{50}) is an approximation, but is sufficiently accurate for practical purposes.

For the data from Table II we have

$$f = \frac{0.30 + 0.55 + 0.80 - 1.50}{0.80 - 0.20} = 0.25$$

$$\text{var}\ (l_{50}) = \left\{ (0.0625)\ \frac{(0.20)\ (0.80)}{82} + \frac{(0.30)\ (0.70)}{26} + \frac{(0.55)\ (0.45)}{21} + (0.5625)\ \frac{(0.80)\ (0.20)}{24} \right\} (0.36)$$

$$= 0.0659$$

$$\text{s.e.}(l_{50}) = \pm\ 0.26$$

The 95 percent confidence limits for l_{50} are given with sufficient accuracy by $22.75 \pm (2)(0.26) = 22.2$ cm, 23.3 cm.

4.1.5 Fitting the Whole Curve by Maximum Likelihood

No simple arithmetic procedures are available for providing unbiased estimates of percentage points other than the 50 percent point. Estimates of other points require the fitting of a curve of precise mathematical specification to the observations. The problem here is not the fitting of the curve but the choice of the curve. Buchanan-Wollaston (1927), for example, has suggested that a length selection curve might be graduated using the cumulative normal frequency distribution (normal ogive) although he did not fit such a curve to his data. The specification of this curve is

$$p_l = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{l} e^{-\frac{1}{2}\sigma^2 (l-\mu)^2} dl$$

An alternative symmetrical curve is provided by the logistic, which is specified by

$$p_l = \frac{1}{1 + \exp\{-(\alpha + \beta l)\}}$$

A possible asymmetrical curve which might be employed is the Gompertz curve

$$p_1 = \exp [-\alpha.\exp(-\beta 1)]$$

The following is a detailed account of the fitting of the logistic curve by maximum likelihood. Essentially, the procedure is to transform the selection curve into a straight line by replacing the observed proportions retained at each length (p) by quantities called logits ($= \ln p/1-p$). Since the sampling variation of a proportion is not the same for all proportions it is necessary when fitting the line exactly to employ different weighting coefficients for different values of L.

First, a provisional line is fitted by eye; then, using the weighting coefficients, adjustments to the slope and intercept of this line are calculated. If necessary, the adjusted line may be used to provide further adjustments.

Fitting the logistic equation by maximum likelihood is made much easier by using tables of the logit transformation (see, e.g., Fisher and Yates (1963), Table XI, which is given here as Table VI).

As an illustration, a logistic curve has been fitted to some original data from a covered cod-end experiment given in Table III. In that table, columns (1)-(4) are the basic data. X represents the length intervals, here chosen as of 2 cm, and n is the total number of fish caught at each length interval, cod-end and cover combined. r is the number of fish at each length interval retained in the cod-end, and p is the proportion of the total catch at each length interval retained in the cod-end, i.e., $p = \frac{r}{n}$. Columns (5)-(11) are the calculations based on columns (1)-(4).

In column (5) the logits corresponding to the observed values of p in column (4) are entered. Alternatively, the data as percentages may be plotted on logistic graph paper and and entries in column (5) omitted. The logits are plotted on ordinary graph paper and the best fitting line is drawn by eye (Figure 13). Alternatively, a line may be drawn by eye to the percentage points on the logistic graph paper. The expected logits, L, are read from this line and entered in column (6). The proportions, P, corresponding to values of L are read from Table VI and entered in column (7). The weights, w, corresponding to the values of L are read from Table VII (Fisher and Yates, Table XI.1) and entered in column (8). In columns (9), (10) and (11) are entered the values of nw, nwx and nP.

The quantities shown below Table III are next found.

The equation of the original line drawn by eye is

$$\frac{L + 0.82}{x - 23.5} = \frac{1.20 + 0.82}{31.5 - 23.5} \qquad \text{.....(i)}$$

$$\text{or} \quad L = -6.75 + 0.2525x \qquad \text{.....(ii)}$$

The provisional values for the slope and intercept are thus 0.2525 and -6.75 respectively. The adjustments, given below Table III, are -0.0087 and +0.24, so that the second estimates of those parameters are

$$b = 0.2525 - 0.0087 = 0.2438$$

$$a = -6.75 + 0.24 = -6.51$$

and the equation of the adjusted line is

$$L_1 = -6.51 + 0.2438x \qquad \text{.....(iii)}$$

By putting $x = 23.5, 25.5, \ldots, 31.5$ in equation (iii) a new set of expected logits (L_1) are obtained. These may be used in a second cycle of calculations to provide further corrections to the values of the slope and intercept, but this will not usually be necessary.

After transforming the values of L_1 back to proportions P_1, the expected number of fish retained in each length group can be estimated by multiplying each P_1 by the total number of fish in the appropriate group. The product values nP_1 may be compared with the actual number of fish retained (r). If r and nP_1 differ appreciably and in a systematic way, the validity of the logistic curve as an adequate representation of the selection curve is questionable. If the deviations, though large, are not systematic, the hypothesis of linearity of the transformed relationship may be accepted, but, in this case, all estimated variances are too small. The significance of the deviations of r from their expectations nP_1 may be tested by calculating the quantity $(r - nP_1)^2/nP_1(1 - P_1)$ for each class interval and summing the values obtained. This sum

$$\chi^2 = \sum \frac{(r - nP_1)^2}{nP_1(1 - P_1)} \qquad \ldots\ldots \text{(iv)}$$

is approximately distributed as a χ^2 variate with degrees of freedom (f, say) equal to two fewer than the number of length intervals employed in the analysis. Should the value of nP_1 in any class be less than 5 the χ^2 approximation may be adversely affected and the data for this class should be combined with those for the neighbouring class or classes to give a value of nP_1 for the combined classes greater than 5. This is not a hard and fast rule (Cochran, 1936). The modified value of χ^2 thus obtained may then be tested as a χ^2, the degree of freedom being two fewer than the final number of classes involved in calculating χ^2.

The calculation of χ^2 for the data given in Table III is laid out in Table IV. The values of L_1 given in column (4) have been obtained from equation (iii) and P_1 from Table VI (Fisher and Yates' Table XI). The rest of Table IV is self-explanatory. The value of χ^2 obtained, 1.156, is approximately distributed as χ^2 with 3 degrees of freedom. Reference to a table of the percentage points of the χ^2 distribution shows that this value is not significantly large and so the line (iii) may be regarded as fitting the observed data satisfactorily.

From equation (iii) an estimate of the 50 percent point of the selection curve is obtained by placing L equal to zero and solving for x. This gives

$$x_{50} = \frac{6.51}{0.2438} = 26.70 \text{ cm}$$

An adequate approximation to the variance of this estimate is

$$\text{var } (x_{50}) = \frac{1}{b^2}\left\{\frac{1}{A} + \frac{(x_{50} - \bar{x})^2}{S(nwx^2)}\right\} \qquad \ldots\ldots (v)$$

where $\bar{x} = B/A$.

Inserting the appropriate values in (v) gives

$$\text{var } (x_{50}) = 0.1901, \quad \text{s.e.}(x_{50}) = \sqrt{0.1901} = 0.436$$

Thus, approximate 95 percent fiducial limits for the 50 percent point are 25.83 and 27.57 cm. (It would normally be quite sufficient to quote these as 25.8 and 27.6 cm respectively.)

Had the value of χ^2 been significantly large, it would have been necessary to multiply the expression given in (v) by the factor χ^2/f to give var (x_{50}). In this situation, when setting fiducial limits, the standard error should be multiplied by the value of Student's t for f degrees of freedom and not by the appropriate normal deviate (e.g., 1.96 for 95 percent limits).

When adopting this method of fitting selection curves, it will often be found necessary to ignore data giving percentages less than 10 percent and greater than 90 percent, since the tail regions, especially the lower one, of selection curves often show very irregular fluctuations and systematic deviations from a logistic curve pattern.

4.2 <u>Comparison of Methods of Fitting Selection Curve</u>

The previous section dealt at some length with especially the statistical aspects of working up selection experiment results. But it must be stressed that, whatever method is used, the quality of the results will still be no better than that of the original data. Rigorous statistical treatment is not a substitute for inadequate data. In general, it will be found that if the selectivity of a gear is not fairly clearly indicated by the initial processing of the data, then the data themselves are not good enough to warrant other than the simplest treatment. However, it is to be noted that the simplest methods both of fitting a selection curve (by eye - see Section 4.1) and of combining results within an experiment and between experiments (by taking a straightforward mean - see Section 4.4) are usually in themselves quite adequate to do justice even to reasonably good selectivity data.

On the assumption that the logistic is an appropriate specification for a selection curve, the method of fitting by maximum likelihood described in the previous section yields the most efficient estimates of the parameters of the curve. In particular, the 50 percent point is most efficiently estimated by this method; others such as the method of moving averages, yield less efficient estimates. However, the additional computational labour of the maximum likelihood method over other methods and the need for tables of logits and weighting coefficients detracts somewhat from its use, and the employment of simpler methods is further enhanced if they yield estimates close to those given by the maximum likelihood method.

Of the simpler methods, fitting by eye has the disadvantages of being entirely subjective and providing no estimate of the accuracy of the fitted curve. Drawing a straight line by eye after transforming the proportions to normal deviates or probits has the same disadvantages, but has the comparative superiority over direct curve drawing in that straight lines are generally easier to draw than curves. The use of unweighted moving averages provides an unbiased estimate of the 50 percent point and permits evaluation of the error of the estimated 50 percent point.

Investigation has been made of comparative estimates of 50 percent points obtained from two sets of data (ICES, 1971). The first was of fifteen actual selection curves fitted by: (a) the maximum likelihood method, (b) the unweighted linear regression method over the selection range, and (c) the three-point moving average method. The second set was of nine actual selection curves fitted by the same three methods plus a fourth, that of drawing the curve by eye. Within each set the results referred to the same cod-end. Taking both sets of comparisons together, all three of the simpler methods gave estimates of the 50 percent points close to those given by the maximum likelihood method. The average values of the variances of the maximum likelihood estimates of 50 percent lengths indicated a percentage standard deviation of between 1.1 and 1.3 from a single set of data, which is a very small component of error. The percentage standard errors of the unweighted linear regression estimates in the two sets of curves were slightly larger at 1.1 and 1.7. The variances of estimates using the moving average method were similar in some cases to those of the above two methods but were mostly higher, sometimes appreciably so. The differences between 50 percent point estimations by seven different persons fitting curves by eye were very small.

It may be concluded from the results of this investigation that, with data of the type examined here, unbiased estimates of 50 percent points can be obtained by eye. Such estimates are very close to those obtained by the method of maximum likelihood, and differences between individuals are likely to be very small indeed, so that eye estimation provides a satisfactory substitute for the maximum likelihood approach. Fitting a straight line by least squares is slightly easier and quicker than a complete maximum likelihood approach but this method cannot really be preferred to eye estimation and is not a completely satisfactory substitute for maximum likelihood fitting of either a logistic function or Gaussian distribution function. The moving average method is not to be recommended generally. It can, even with moderately good data, occasionally give rise to ambiguity by providing more than one 50 percent point for a given set of data. It only estimates the 50 percent point without bias and the calculation of the variance of the estimated 50 percent point is tedious.

A further interesting feature of the eye method, brought out in the investigation was that all seven people drew fairly similar curves over the whole range. This study has also shown that the percentage standard error in the 50 percent retention length (or selection factor) estimated by somewhat elaborate statistical techniques is of the order of 1 to 2 percent, while that of the selection range is of the order of 10 percent. This sort of accuracy can be obtained, in general, without recourse to statistical procedures simply by drawing free-hand curves by eye, although there is evidence that selection ranges estimated from eye-fitted curves may be smaller than by other methods, e.g., by maximum likelihood method of fitting the logistic curve.

4.3 Assessing Estimates

From the investigation referred to in Section 4.2, any set of data giving a percentage standard error in an estimate of the 50 percent retention length much in excess of 2 percent, say $\geq$ 5 percent, may be taken as unreliable. Any data suspected of being unreliable would have to have the accuracy of any estimate drawn from it estimated, and this could be done by either submitting the data to a complete statistical treatment or by having several people independently fitting curves by eye.

Haul-to-haul variability is a much larger component of error than within-haul variability, so that errors in estimation for a single haul are relatively unimportant in comparison with other errors. In a set of data covering a series of hauls there may be some conspicuously outlying observations. If the experiment has been conducted carefully and proper records kept, the cause of some of these may sometimes be obvious and then they may be safely rejected. But where no cause for the occurrence of a divergent observation can be identified, then the best procedure is to carry out the analysis of the data both with and without the outlying observations. If the general conclusions are different in the two analyses, then no firm conclusion is warranted.

Generally, the component of variance between experiments has been found to be comparable with that within experiments. This, for trawl cod-end experiments, commonly corresponds to a percentage standard deviation of 5 percent so that, for example, the 95 percent confidence limits for a mean selection factor of 3.47 would be at $\pm$ 0.11, i.e., at 3.36 and 3.58.

4.4 Combining Estimates

In some covered cod-end experiments it may be impossible to derive selection curves for any, or most, of the individual hauls, due to low catches. Such data may, however, yield a selection curve if the individual cod-end and cover catches, on separate summation, give sufficient numbers of fish for the reliable determination of percentage retentions. If all hauls in an experiment are summed in this way no estimates of the variability in the parameters of the curve are available. Therefore, when individual hauls cannot provide selection curves they should, if possible, be summed in groups to provide as many selection curves as possible. The extent of the sampling error in, say, the estimated 50 percent points may then be gauged from the separate values, with or without weighting as appropriate. Summations of this sort should only be attempted when it seems certain that the population of fish being sampled has not changed during the course of the experiment.

It will usually be the case that, when combining average values of 50 percent retention length or selection factors from different experiments, the results from different experiments will be less homogeneous than results from the same experiment.

When several estimates of, say, the 50 percent retention length, or selection factor, for a particular species of fish and a particular cod-end have been obtained from a series of hauls in one experiment or from several experiments, it will often be desirable to quote a single average value. Two possible forms of average may be considered. If $x_1, x_2, \ldots, x_n$ are n estimates they may be combined to give a simple unweighted ----

$$\bar{x} = (x_1 + x_2 \ldots + x_n)/n$$

or a weighted mean

$$\bar{x}_w = (w_1 x_1 + w_2 x_2 + \ldots + w_n x_n)/(w_1 + w_2 + \ldots + w_n)$$

where $w_1, w_2, \ldots, w_n$ are weighting factors.

If the weighting factors are chosen to be proportional to the reciprocals of the variances of the estimates, then $\bar{x}_w$ will have a smaller variance than any other average. If the variances of the estimates are all equal, then the unweighted and weighted means will be equal and their variances will be equal. By using the reciprocals of the variances as weighting factors, more weight is given to the more accurate estimates. For the weighted mean to be a valid average the weighting factors must not be associated with the estimates; for example, if the less accurate hauls tend to give lower selection factors, a weighted mean could be misleading. If the range of variances is very large, as it can be when the sizes of catches varies markedly, it is advisable to set an upper limit to the weighting factors, any weighting factor exceeding this limit being replaced by the limiting value.

Besides the methods of unweighted mean and weighted mean using the inverse of the variance, estimates of selection factors (or of 50 percent retention lengths) can be combined by calculating the mean weighted by the number of hauls corresponding to each selection factor or by calculating the mean weighted by the three components: (1) number of hauls in experiment, (2) duration of hauls, and (3) numbers of fish within the selection range. This latter method takes account not only of the frequency of occurrence of each value of the selection factor but also of the conditions of the experiment under which it is obtained. In it the weighted value of the mean selection factor is obtained by the formula:

$$\bar{k}_s = \frac{\Sigma n_i t_i N_i k_i}{\Sigma n_i t_i N_i} = \frac{n_1 t_1 N_1 k_1 + n_2 t_2 N_2 k_2 + \ldots + n_n t_n N_n k_n}{n_1 t_1 N_1 + n_2 t_2 N_2 + \ldots + n_n t_n N_n}$$

where $\bar{k}_s$ is the mean weighted trawl selection factor;

$n_1, n_2 \ldots n_n$ are the number of hauls in the first, second and n^{th} experiments;

$t_1, t_2 \ldots t_n$ are the durations of haul in the first, second and n^{th} experiments;

$N_1, N_2 \ldots N_n$ are the numbers of fish within the selection range in the first, second and n^{th} experiments;

$k_1, k_2 \ldots k_n$ are selection factors in the first, second and n^{th} experiments.

ICES Cooperative Research Report Series A, No. 25, includes tables of extensive data combined by each of the four methods described above. The resultant values are generally in very close agreement. So, for many purposes, the average values of selection factors can be combined satisfactorily simply by calculating the unweighted

4.5 Comparison of Selection Factors

It has already been noted that the two main components of variance in an experimental value of a 50 percent selection length, or a selection factor, are the between-haul within-experiment and the between-experiment components. In the ICES Cooperative Research Report, A, 25, collected data for trawls in the North Atlantic region comparing selection factors for different materials the coefficients of variation of both components are of the order of 5–10 percent, say 7 percent on average. Thus, for a cod-end material with an average selection factor of, say 3.3, the variance of a single determination would be 0.1067. If it is assumed that experimental values are normally distributed and further that such values are representative of the actual factors operating in the commercial fleets then 95 percent of all hauls made in a given period of time would have actual selection factors lying approximately between 2.7 and 3.9. Furthermore, if the average selection factor for another cod-end material were 3.6 (say), and if selection factors for this material were also normally distributed with a variance of 0.1067 (standard deviation = ± 0.33) then some 18 percent of all commercial hauls by the second material would have actual selection factors below 3.3, the mean of the first material. There will in fact be a considerable overlap of two distributions with means differing by only 10 percent. This is quite a different matter from the question as to whether or not the mean selection factors for two different materials are really different or not. The problems of establishing the existence of differences in mean selection factors for different materials have been discussed by Gulland (1964). However, greater precision in mean values is achieved with the accumulation of more and more data. ICES Cooperative Research Report, A, 25, gives the average cod selection factor for double polyamide as 3.83 ± 0.09. If the mean selection factor for another cod-end material were established with the same accuracy, then it would be deemed to differ significantly from 3.83 if it were some 5–6 percent higher or lower.

4.6 Calculation of Gillnet and Hook Selectivity

Estimating gillnet selectivity curves is difficult. The basic principles were set down sixty years ago by Baranov (1948); yet until 1957 work was almost entirely limited to estimating selection ranges and modal lengths (Andreev, 1955; Konda, 1966). In 1957 Holt (1963) proposed a method of estimating complete selectivity curves; this stimulated much further work which is continuing today (Regier and Robson, 1966; Hamley and Regier, 1973).

Four types of approach have been used: (1) Direct estimates; (2) Indirect estimates, including the "iterative estimates" of Regier and Robson (1966); (3) DeLury method, and (4) Inference from girth measurements. The first three are different ways of analysing comparative catch data, the fourth predicts selectivity from observations of size and shape of fish body.

On the few occasions hook selectivity has been estimated, same methods have been used as for gillnets.

4.6.1 Direct Estimates

These are the most reliable estimates available today. They require knowing the size frequency distribution of the fish population, and estimate selectivities by the proportions of fish caught from different size classes. If there are N_j fish in size class j, and C_{ij} of them are caught when mesh i is fished with effort f_i, then the estimated selectivity $\hat{s}_{ij}$ of mesh i to size class j is:

$$\hat{s}_{ij} = \frac{C_{ij}}{N_j f_i}$$

To know the N_j, either the fish population is marked or it is sampled with another gear whose selectivity is 1

The size distribution of fish must remain known throughout the period of gillnetting. In fishing a marked population, tagging mortality may be a problem if it is greater for smaller fish. Another problem is that, if the gillnetting takes a major portion of the fish population, then those size classes taken most efficiently are reduced most rapidly. To account for that, one can use the mean of daily selectivity estimates, weighted by the numbers of survivors:

$$\hat{s}_{ij} = \frac{\sum_t C_{ijt}/f_{it}}{\sum_t N_{jt}}$$

where N_{jt} fish of size class j are alive at the start of day t, and C_{ijt} of them are caught on that day when mesh i is fished with effort f_{it}.

If the size distribution of fish is determined by fishing with another gear, caution is needed in assuming the second gear to be "unselective". For example, trawls are often assumed to be unselective for fish larger than some size of "maximum retention"; however, an example to the contrary is in Myhre (1969: Table 6) who caught no halibut over 114 cm long in trawls even though longlines on the same grounds caught them up to 184 cm long.

4.6.2 Indirect Estimates

These are based on comparing the catches of a single size class of fish by nets of different mesh sizes. Because all mesh sizes are equally likely to be met by the fish, catches are proportional to selectivities, and plotting catches against mesh sizes gives an unbiased estimate of the relative selectivity curve of the different meshes to that single size class of fish. Regier and Robson (1966) termed such curves "Type B selectivity curves", and called the usually seen curves that show the selectivity of one mesh size to different sizes of fish "Type A selectivity curves". The indirect estimates start by comparing catches of one size class by different meshes, and obtain Type A curves either graphically via Type B curves (McCombie and Fry, 1960; Ishida, 1962) or by algebraic manipulation (Holt, 1963).

The difficulty with all indirect estimates is that the heights of Type B curves cannot be compared, because the relative abundances of fish in different size classes are not known. To allow a solution, the selectivity curves for all mesh sizes are assumed to have the same shape and height. But there is evidence that the heights of selectivity curves increase with mesh size (Hamley and Regier, 1973); therefore the present indirect estimates are biased. Until they can be revised, gillnet selectivity should be estimated by other methods.

Because of their bias, the indirect estimates are not described here in detail. They were reviewed by Regier and Robson (1966); to that should be added that Ishida later simplified his method by plotting catches on a logarithmic scale (Manzer et al., 1965), and that Kitahara (1971) used a method that combines features of McCombie and Fry's and Ishida's.

4.6.3 DeLury Method

In theory, any method of estimating fishing mortality can also estimate selectivity, if the calculations are done separately for each size class of fish. In practice, it may be difficult to obtain adequate samples and to assure that catchability remains constant.

The DeLury method estimates selectivity from the decrease in catch per effort as the population is reduced by heavy fishing (Hamley, 1972). The method requires assuming that catchability remains constant. Selectivity can be estimated from an experiment with a single mesh size, using either one of two formulae:

$$U_{jt} = s_j N_{jo} - s_j \sum_t C_{jt}$$

$$\ln(U_{jt}) = \ln(s_j N_{jo}) - s_j \sum_t f_t$$

where, for size class j, N_{jo} is the initial population, U_{jt} is the catch per unit effort during the period t, and $\sum_t C_{jt}$ and $\sum_t f_t$ are the catch and effort accumulated to time t. The selectivity s_j is estimated by linear regression of either U_{jt} on $\sum_t C_{jt}$ or $\ln(U_{jt})$ on $\sum_t f_t$.

If several mesh sizes are fished simultaneously and their catches during period t are independent, the selectivity of each mesh size i can be estimated by regressing U_{ijt} on $\sum_i \sum_t C_{ijt}$ in the formula

$$U_{ijt} = s_{ij} N_{jo} - s_{ij} \sum_i \sum_t C_{ijt}.$$

4.6.4 Inference from Girth Measurements

For species that are seldom caught tangled, girth measurements allow preliminary estimates of selection range and modal length. This is because to be wedged or gilled, a fish must penetrate into a mesh beyond the gillcovers but not pass completely through. Therefore the selection range of a mesh size includes all fish whose maximum girth is greater but head girth smaller than the mesh perimeter. To be accurate, one must also consider the stretching of mesh and compression of fish body (especially at maximum girth) as the fish struggles to get through the net. The amount of stretching and compression varies with the strength of fish, softness of its body, and the material and thickness of net twine; it may be about 5–10 percent and can be estimated by measuring girths at netmarks (Baranov, 1948; Konda, 1966).

As a first approximation, the modal length is that length at which the maximum girth is 1-25 times the mesh perimeter (Andreev, 1955; McCombie and Berst, 1969). Alternately, the modal length can be estimated as that length at which the mesh perimeter equals the average of the head and maximum girths (Strzyzewski, 1964).

A few attempts have been made to predict complete selectivity curves (Farran, 1936; Sechin, 1969a, b; Kawamura, 1972). The principle is that girth selection is knife edged, but length selection is not, because all fish of the same length do not have the same girth. Thus, for each length class, selectivity is estimated by the proportion of fish whose head girth is smaller but maximum girth larger than the mesh perimeter. The results have not all been satisfactory, partly because some fish are caught tangled and partly because all fish of the same girth may not be equally likely to be caught - for example, longer fish of the same girth are stronger and can penetrate deeper into the mesh (Lander, 1969).

All inference from girth measurements should be treated as preliminary only. As these methods do not predict any captures by tangling or wedging on head, their usefulness is limited to species that are seldom caught except by gilling or wedging on body.

4.6.5 Compound Selectivity Curves

When fish are caught in nets in several ways, selectivity curves may be multimodal or otherwise complex. Such a curve can be treated as the sum of simpler component curves, one for each way of capture. For mesh size i and fish size class j, the numbers of fish C'_{ij} caught in some particular way (e.g., gilled) are in the same proportion to the total catch C_{ij} as the selectivity s'_{ij} due to being caught in that way is to the total selectivity s_{ij}:

$$C'_{ij}/C_{ij} = s'_{ij}/s_{ij}.$$

If records are kept of how each fish is caught, the total selectivity curve can be estimated by either (1) estimating separately, then summing, the component selectivity curves for each way of capture (Hamley and Regier, 1973); or (2) estimating the component selectivity curve due to one way of capture, then multiplying it by the ratio C_{ij}/C'_{ij} (Olsen and Tjemsland, 1963).

4.6.6 Design of Nonselective Gillnets

Gangs containing gillnets of several mesh sizes have been used for a long time to obtain samples of a wide size range of fish. Occasionally special research nets have been built, composed of small sections of different meshed nets in a Latin Square arrangement (Houser and Ghent, 1964).

If such nets or gangs of nets are to be "nonselective" and catch all sizes of fish in their natural proportions, the mesh sizes must be chosen according to their selectivities to the target species (Ishida et al., 1966). If nets of smaller mesh are less efficient, their surface area must be appropriately larger. Because selectivity curves are species-specific, it may not be possible to design nets that are nonselective to all species of fish collected.

As discussed in 3.6.1, setting nets in gangs can cause problems, namely that some positions in the gang may be better than others, and that the catch in one net may be affected by the mesh size of adjacent nets.

5. FACTORS OTHER THAN MESH AND HOOK SIZE AFFECTING SIZE SELECTION

5.1 Cod-end Selection

5.1.1 Material and Construction

A difference in the selective properties of different materials was observed when comparisons were made of results for manila trawl cod-ends and cotton seine net cod-ends (Graham et al., 1954; Lucas et al., 1954). Boerema (1956) also found a difference in the selection of hemp and manila trawl cod-ends. These findings led to what was termed the "light trawl" problem, a loose term used in discussion of the observation that cod-ends of light material (cotton, hemp, thin single manila) have higher selection factors than cod-ends made of heavy or double manila and sisal.

Since 1954 considerable attention has been paid to the study of cod-end material in relation to mesh selection. Great impetus has been given to this work by the rapid expansion in the use of synthetic fibres for fishing twine manufacture.

Of the commonly used modern trawl materials it has generally been found that cod-ends made from polyamide have the highest selection factors, followed in descending order by polyester, polypropylene, polyethylene and manila. However, it is by no means certain that the chemical nature of the material alone is chiefly responsible for its selective properties and, in particular, it is most likely that the form of construction of twine from the materials (e.g., twisted or plaited, and how tightly twisted) plays an important part in determining its selective properties (ICES, 1971).

Selection factors very occasionally appear to vary with mesh size even when the same type of material is used in making the different sizes of mesh. This may be an effect of using only one size of twine when, as mesh size is increased, the size of knots remains the same but the mesh bar lengths increase, thus making more flexible netting. The common practice of increasing twine diameter with mesh size tends to cancel out any such effect, hence the rarity of the phenomenon.

5.1.2 Chafing Gear

It has been common practice for big trawlers to use cod-ends strengthened and protected by extra netting attached on the outside of the upper side, as well as the usual underside protective "false bellies" or hides. These so-called topside chafers can, according to their design and rigging, seriously affect the cod-end selectivity by masking the meshes. If they are of netting like that from which the cod-end is made, and are of the same dimensions as the topside of the cod-end and laced to the cod-end along all four edges, then they can reduce selectivity by about 10 percent. If they are of netting of twice the cod-end mesh size and are not laced to the cod-end at the cod-line, then their effect on selectivity is practically negligible (Strzyzewski, 1967).

5.1.3 Method of Fishing

A light trawl worked by a small trawler is likely to have a different cod-end mesh selectivity from that of a heavy trawl with the same cod-end mesh size worked by a big ship. This will be due partly to the differences in twine size and construction used in the netting and partly to different speeds through the water. The same will apply to a comparison of selectivities between trawls and seines.

5.1.4 Other Factors

Several investigators have found an association between catch size and selection, the selection factor tending to be lower when catches are high. Thus Clark et al. (1958) report that in the Northwest Atlantic area the 50 percent point for haddock may decrease by as much as 5 cm from light to heavy catches, but they do not specify the actual range of catch sizes

over which this decrease has been found. Lower selection factors for cod with large catches were noted in covered cod-end experiments made in the Arctic waters of the Northeast Atlantic (ICES, 1964). Thus, for example, in one series of hauls dealt with by them they found selection factors for this species of 3.5, 3.0 and 2.8 from hauls with average catches of 340 kg, 860 kg and 1 800 kg respectively. On the other hand, no such relationship was found in data from alternate haul experiments. Other writers who have found evidence of lower selection factors for hauls with large catches are Beverton (1964), von Brandt (1960), Bohl (1961) and Hodder (1964). This reduction in selection factor may be due to changes in mesh shape, the blocking of meshes or changes in fish behaviour with large catches. The effect, however, appears to have been detected only in covered cod-end hauls and may be partly or wholly due to the presence of a cover. The subject merits further careful study in view of its important bearing on the application of the results of selectivity experiments to commercial fisheries, because the level of commercial trawl catches is generally higher than that in selectivity experiments.

Cassie (1955) noticed that covered cod-end hauls with bigger catches showed sharper selection than did hauls with small catches and explained this as the effect of meshes just in front of the accumulating catch being held more firmly open when the cod-end was partially distended.

There is some evidence that selection factors increase with increasing duration of tow in trawl hauls (Clark, 1957b; Beverton, 1964). This could be explained by the fact that most fish make not one but repeated attempts at escape, the increase in towing time thereby providing a greater chance of escape. This will, however, generally be accompanied by an increase in size of catch and these two factors tend to act in opposing directions. In analysing the results of experiments designed to test the effect of tow duration on selection appropriate care must therefore be taken to eliminate from the comparisons any effect of variations in catch size.

Saetersdal (1958, 1960) found a decrease in selection factor with increasing towing speed in the case of Arctic cod. In conducting selectivity experiments the results are to be applied to specific commercial fisheries, it is therefore recommended that the speed of tow should be the same as in the commercial fishery.

5.2 Gillnet Selection

Other than mesh size, the most important characteristics of a gillnet are its visibility, stretchability of meshes, and tangling capacity. These affect mainly the efficiency of the net (height of selectivity curve), but may also affect the selectivity (shape and mode of selectivity curve).

Less visible nets can catch many times more fish (Andreev, 1955). Parrish (1969) reports that in aquarium experiments nets of smallest mesh, thickest twine and brightest colour were avoided the most by herring, and that the avoidance decreased with decreasing light intensity. Monofilament nets are nearly invisible in water and herring swam into them even in daylight. More visible nets tend to catch fewer large fish, presumably because larger, older fish are more cautious (Steinberg, 1962).

The material and thickness of net twine affect the probability of holding fish that have swum into the net. Meshes of a more elastic twine can be stretched to a larger size by a struggling fish, resulting in capture of a larger average size of fish and a wider selection range (Ishida, 1969). Nets of looser hanging or more flexible twine tangle more fish, also resulting in capture of a larger average size of fish and wider selection range (Mohr, 1965). Nets of thinner twine are less visible, easier to stretch and more flexible; they catch larger fish as long as the twine is not thin enough to be broken by those larger fish (Hansen, 1974).

The way the nets are used can also be important. The location and depth of fishing may affect the sizes caught because different sized fish may occupy different habitats. Sometimes the way of hauling is important: large herring are often meshed loosely by their heads and fall off easily, more of them can be landed if the side of net with most herring is kept on top (Farran, 1936). Saturation decreases the efficiency of a net, possibly it also affects selectivity (Baranov, 1948; Kennedy, 1951).

5.3 Hook Selection

Size selectivity of a hook depends mainly on its gape; catch efficiency may depend on its shape and shank length. Forster (1973) had better longline catches of deep-sea fish with hooks that had incurved points; Takeuchi and Koike (1969) caught more fish with hooks that had shorter shanks. Strength of the hooks is important if large fish may break or pull straight the smaller hooks.

Larger baits tend to catch larger fish, but there are no data to compare the importances of hook and bait sizes. Probably hook size is the more important. Other factors to consider are the attractiveness and durability of bait, availability of natural food, and abundance of fish including secondary species that are caught incidentally (Clark, 1960).

Selectivity may also be affected by the way the baits are presented, because larger fish may forage over larger areas or compete for food more aggressively. Thus, similar hooks and baits spaced at wider intervals caught larger average sizes of halibut (Skud, 1972).

6. PRESENTATION OF RESULTS

When reporting the results of selection experiments, it is essential that all relevant data relating to the methods employed in collecting and analysing the results be clearly recorded in a tabular form which will be readily understood by other workers. The following list of information which is essential in all reporting is based on the recommendations of the ICES Mesh Selection Working Group (ICES, 1964) which was later amended and revised by the ICES Comparative Fishing Committee, at its 52nd meeting, 1964 (ICES, 1965).

As it stands, the following list meets also the case in which data from several hauls are combined to give a simple selection result. The most appropriate way of grouping hauls must, of course, be left to the discretion of the scientist.

This list is not an exhaustive one, and any special circumstances applying to the tests, or supplementary information such as girth measurements, must be mentioned. If results for individual hauls are to be given, the presentation can be adapted accordingly.

ITEM

1. Ship
   Size (length or gross tonnage) of the vessel employed and the engine horse-power should be quoted.

2. Gear
   Full description of the gear under consideration should be given. This should include the more important dimensions (e.g., ground rope dimension of trawl, size of nets for gillnets, etc.) and the material used in its construction.

3. Date

4. Time
   In view of the substantial differences of selectivity in daylight and darkness, the time of day should be given and, when possible, light meter readings at the depth at which the gear is operating should be taken and reported. The weather conditions prevailing during the experiments should also be mentioned with particular reference to the state of the sea.

5. Locality
   The fishing grounds should be specified and details given of the nature of the bottom.

6. Depth range

7. Cod-end material
   (Including runnage, braiding, treatment, Tex. No.)

8. Type of mesh gauge
   The recommended gauge for the North Atlantic is the ICES gauge which operates at a pressure of 4 kg (Westhoff, Pope, Beverton, 1962). If another type of gauge is employed it must be described and the pressure at which it operates should be exactly specified.

9. Mesh size .... Mean: to nearest mm
Range: in mm
S.E. of mean: to nearest 0.1 mm
No. of measurements

In gillnet experiments the hanging coefficients, twine, material, diameter, colour, of the nets should be stated. In reporting experiments with hooks, the dimensions of the hooks, hook shape, baiting, and their spacing along the lines should be stated.

10. Experimental method
A description of the experimental method employed should be given including details of experimental design. The total number of fishing operations made should be stated.

11. Dimensions, material and mesh
Size of cover.

12. Species

13. 50 percent retention length .... to nearest mm

14. Selection factor .... S.F. to 1 decimal place
(S.E. of S.F. to 2 decimal places)

It is intended that the S.E. of the mean selection factor should be calculated from selection factors obtained from individual hauls. If the data are insufficient, the S.E. cannot be given.

15. 25-75 percent selection range .... to nearest mm

16. Number of fish of the species studies in selection range, in cod-end and cover separately.

17. Average weight per haul of all fish species (including that studied) in cod-end and cover separately .... in kg

If there are marked variations in the catch composition of the hauls being summarised, it is advised that the main composition of each should be stated separately. *

18. Quantity and composition of other catch (including weed, sponge, crustacea, etc.) .... in kg

* same applies as in item 17

19. Number of hauls

20. Average duration of haul .... h and min

21. Towing speed (speed through water) .... kn

GLOSSARY OF TERMS

This glossary includes some terms used in this manual which are not defined or explained in the text and which are not in common usage internationally.

Anchor and fly-dragging methods of Danish seining: in the anchor method the ropes and net are heaved in to an anchored vessel; in fly-dragging they are heaved into a vessel making headway under power.

Belly and Batings (of. a trawl net): the tapered middle part of the net leading to the cod-end; "belly" sometimes refers to the whole of this part, but sometimes to only its underside part, in which case the upperside is known as the "batings".

Blinder: small meshed netting on the inside of a fishing net to prevent the passage of fish through that net.

Chafer: material (sometimes netting) attached to the outside of a fishing net, primarily to prevent abrasion damage to the net either while it is being towed or while it is being hauled on to the fishing vessel.

Catching capacity (of a gear): the ability of a gear to catch fish which are available to it; this can be expressed quantitatively in absolute or relative terms.

Direction in netting: T-direction is the direction of the general course of the netting yarn, i.e., "across the width" of the netting; N-direction is at right angles to the general course of the netting yard, i.e., "along the length" of the netting.

Dutch shuffle: a method of obtaining a truly representative sample from a catch. For example, if a quarter of the catch is to be taken as a sample, four container units (e.g., baskets or groups of baskets) are set out and from the collected catch a few fish at a time are tipped, in sequence, into each of the four container units; then, when all of the catch has been distributed, one of the four filled container units is taken as the sample. The distribution of the contents of all the container units amongst a further four units may be repeated before the sample is withdrawn.

Flatfish: fish of flattened body shape, with cross-sectional width very much greater than thickness, e.g., pleuronectids and rays.

Floppa and pockets: in a trawl the floppa is a piece of netting attached inside the net at the mouth of the cod-end serving to allow easy passage of the fish into the cod-end but preventing their passage forward again; pockets are a form of one-way valve made at either side of the after end of the belly of the net by a line of loose lacing of upper side to lower side of the belly netting from the selvedge inward toward the mouth of the cod-end.

Haul (noun): one single operation of the gear; for a trawl, the duration of haul is taken as the time from the end of paying out the full length of warp to commencement of hauling in.

Roundfish: fish other than flatfish, which are approximately round or oval in cross-section, e.g., cod, tuna.

Shoot and haul (verb): to pay out and set the gear into action and to recover it again.

Valid haul: a haul successfully completed free from any defect, and satisfying the design criteria of the experiment.

Vulnerable: of fish, those available which are open to attack by the gear.

Zone of action of gear: the water swept by moving gear, e.g., that between the sea-bed and headline height and between the two otterboards of a bottom trawl, or the water within which fish are influenced by the gear, e.g., attracted by bait.

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TABLE I

Working Sheet showing Selection Data for Haddock from Covered Cod-end Experiment

(1) Length (cm)	(2) No. of fish in cod-end	(3) No. of fish in cover	(4) No. of fish in cod-end and cover	(5) Percentage retained
18	0	186	186	0
19	6	194	200	3
20	9	140	149	6
21	17	66	83	20
22	8	19	27	30
23	12	10	22	55
24	20	5	25	80
25	16	2	18	89
26	11	1	12	92
27	7	0	7	100

TABLE II

Working Sheet showing Data for Haddock from Alternate Haul Experiment

Length (cm)	(A) No. of fish in 35 mm cod-end	(B) No. of fish in 87 mm cod-end	(C) $^B/_A$	(D) $^B/_{1.28A}$
24	1	-	0.00	0.00
25	1	-	0.00	0.00
26	3	-	0.00	0.00
27	14	1	0.07	0.05
28	30	5	0.17	0.13
29	49	19	0.39	0.30
30	60	29	0.48	0.38
31	50	51	1.02	0.80
32	70	91	1.30	1.02
33	108	120	1.11	0.87
34	88	118	1.34	1.05
35	84	107	1.27 av. = 1.28	1.00
36	68	78	1.15	0.90
37	37	52	1.41	1.10
38	33	40	1.21	0.95
39	12	17	1.42	1.11
40	5	17	3.40	
41	6	14	2.33	
42	10	10	1.00	
43	1	4	4.00	
44	6	6	1.00	
45	2	2	1.00	
46	1	5	5.00	
47	-	1	-	
	$\sum_{32}^{47} A = 531$	$\sum_{32}^{47} B = 682$	$^{682}/_{531} = 1.28$	

TABLE III

Maximum Likelihood Fitting of Logistic Selection Curve

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
x	n	r	p	Emp. Log	L	P	w	nw	nwx	nP
23.5	75	15	0.20	-0.69	-0.82	0.162	0.5444	40.830	959.505	12.15
25.5	20	6	0.30	-0.42	-0.32	0.345	0.9038	18.076	460.938	6.90
27.5	25	14	0.56	0.12	0.19	0.594	0.9646	24.115	663.162	14.85
29.5	19	16	0.84	0.83	0.70	0.802	0.6347	12.059	355.740	15.24
31.5	12	11	0.92	1.22	1.20	0.917	0.3050	3.660	115.290	11.00

$\sum nw = 98.740 = A$

$\sum nwx = 2554.635 = B$

$\sum nwx^2 = 66665.2065 = C$

$B^2/A = 66094.3891 = D$

$S(nwx^2) = C - D = 570.8174$

$\sum np = 62 = E$

$\sum nP = 60.14 = F$

$E - F = 1.86 = G$

$\sum nxp = 1709.080 = H$

$\sum nxP = 1665.930 = I$

$H - I = 43.150 = J$

$$\Delta b_1 = (J - GB/A) \div S(nwx^2)$$

$$= (43.15 - 48.12) \div 570.8174$$

$$= - 0.0087$$

$$\Delta a_1 = G/A - (\Delta b_1)\ B/A$$

$$= 0.0188 + 0.2251$$

$$= 0.2439$$

TABLE IV

Calculation of Test of Goodness of Fit

x	n	L_1	P_1	Q_1	nP_1	r	$\frac{(r - nP_1)^2}{nP_1Q_1}$
23.5	75	−0.781	0.17	0.83	12.8	15	0.456
25.5	20	−0.293	0.36	0.64	7.2	6	0.312
27.5	25	0.194	0.60	0.40	15.0	14	0.167
29.5	19	0.682	0.80	0.20	15.2	16	0.211
31.5	12	1.170	0.91	0.09	10.9	11	0.010
							$\chi^2 = 1.156$

TABLE V

Comparison of 50% Points obtained by Different Methods of Estimation

Maximum Likelihood	Moving Averages	Linear Regression
24.6	24.5	24.5
26.5	26.6	26.5
25.5	25.7	25.6
21.9	20.7	21.7
23.0	23.0	23.0
25.5	25.7	25.4
18.2	18.2	18.2
21.7	21.6	21.7
27.5	27.5	27.5
22.0	21.8	22.1
25.6	25.6	25.6
24.7	24.5	24.4
28.2	28.5	28.2
31.2	31.1	31.1
32.9	32.5	32.6

TABLE VI

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LOGITS

The Logit or r, z Transformation

p %	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
50	·0000	·0020	·0040	·0060	·0080	·0100	·0120	·0140	·0160	·0180
51	·0200	·0220	·0240	·0260	·0280	·0300	·0320	·0340	·0360	·0380
52	·0400	·0420	·0440	·0460	·0480	·0500	·0520	·0541	·0561	·0581
53	·0601	·0621	·0641	·0661	·0681	·0701	·0721	·0741	·0761	·0782
54	·0802	·0822	·0842	·0862	·0882	·0902	·0923	·0943	·0963	·0983
55	·1003	·1024	·1044	·1064	·1084	·1104	·1125	·1145	·1165	·1186
56	·1206	·1226	·1246	·1267	·1287	·1307	·1328	·1348	·1368	·1389
57	·1409	·1430	·1450	·1471	·1491	·1511	·1532	·1552	·1573	·1593
58	·1614	·1634	·1655	·1676	·1696	·1717	·1737	·1758	·1779	·1799
59	·1820	·1841	·1861	·1882	·1903	·1923	·1944	·1965	·1986	·2007
60	·2027	·2048	·2069	·2090	·2111	·2132	·2153	·2174	·2195	·2216
61	·2237	·2258	·2279	·2300	·2321	·2342	·2363	·2384	·2405	·2427
62	·2448	·2469	·2490	·2512	·2533	·2554	·2575	·2597	·2618	·2640
63	·2661	·2683	·2704	·2726	·2747	·2769	·2790	·2812	·2833	·2855
64	·2877	·2899	·2920	·2942	·2964	·2986	·3008	·3029	·3051	·3073
65	·3095	·3117	·3139	·3161	·3183	·3205	·3228	·3250	·3272	·3294
66	·3316	·3339	·3361	·3383	·3406	·3428	·3451	·3473	·3496	·3518
67	·3541	·3564	·3586	·3609	·3632	·3654	·3677	·3700	·3723	·3746
68	·3769	·3792	·3815	·3838	·3861	·3884	·3907	·3931	·3954	·3977
69	·4001	·4024	·4047	·4071	·4094	·4118	·4142	·4165	·4189	·4213
70	·4236	·4260	·4284	·4308	·4332	·4356	·4380	·4404	·4428	·4453
71	·4477	·4501	·4526	·4550	·4574	·4599	·4624	·4648	·4673	·4698
72	·4722	·4747	·4772	·4797	·4822	·4847	·4872	·4897	·4922	·4948
73	·4973	·4999	·5024	·5049	·5075	·5101	·5126	·5152	·5178	·5204
74	·5230	·5256	·5282	·5308	·5334	·5361	·5387	·5413	·5440	·5466
75	·5493	·5520	·5547	·5573	·5600	·5627	·5654	·5682	·5709	·5736
76	·5763	·5791	·5818	·5846	·5874	·5901	·5929	·5957	·5985	·6013
77	·6042	·6070	·6098	·6127	·6155	·6184	·6213	·6241	·6270	·6299
78	·6328	·6358	·6387	·6416	·6446	·6475	·6505	·6535	·6565	·6595
79	·6625	·6655	·6685	·6716	·6746	·6777	·6807	·6838	·6869	·6900
80	·6931	·6963	·6994	·7026	·7057	·7089	·7121	·7153	·7185	·7218
81	·7250	·7283	·7315	·7348	·7381	·7414	·7447	·7481	·7514	·7548
82	·7582	·7616	·7650	·7684	·7718	·7753	·7788	·7823	·7858	·7893
83	·7928	·7964	·7999	·8035	·8071	·8107	·8144	·8180	·8217	·8254
84	·8291	·8328	·8366	·8404	·8441	·8480	·8518	·8556	·8595	·8634
85	·8673	·8712	·8752	·8792	·8832	·8872	·8912	·8953	·8994	·9035
86	·9076	·9118	·9160	·9202	·9245	·9287	·9330	·9373	·9417	·9461
87	·9505	·9549	·9594	·9639	·9684	·9730	·9775	·9822	·9868	·9915
88	·9962	1·0010	1·0058	1·0106	1·0154	1·0203	1·0253	1·0302	1·0352	1·0403
89	1·0454	1·0505	1·0557	1·0609	1·0661	1·0714	1·0768	1·0822	1·0876	1·0931
90	1·0986	1·1042	1·1098	1·1155	1·1212	1·1270	1·1329	1·1388	1·1447	1·1507
91	1·1568	1·1630	1·1692	1·1754	1·1817	1·1881	1·1946	1·2011	1·2077	1·2144
92	1·2212	1·2280	1·2349	1·2419	1·2490	1·2562	1·2634	1·2707	1·2782	1·2857
93	1·2933	1·3011	1·3089	1·3169	1·3249	1·3331	1·3414	1·3498	1·3583	1·3670
94	1·3758	1·3847	1·3938	1·4030	1·4124	1·4219	1·4316	1·4415	1·4516	1·4618
95	1·4722	1·4828	1·4937	1·5047	1·5160	1·5275	1·5393	1·5513	1·5636	1·5762
96	1·5890	1·6022	1·6157	1·6296	1·6438	1·6584	1·6734	1·6888	1·7047	1·7211
97	1·7380	1·7555	1·7736	1·7923	1·8117	1·8318	1·8527	1·8745	1·8972	1·9210
98	1·9459	1·9721	1·9996	2·0287	2·0595	2·0923	2·1273	2·1649	2·2054	2·2494
99	2·2976	2·3507	2·4101	2·4774	2·5550	2·6467	2·7587	2·9031	3·1063	3·4534

The logit transformation, $z = \frac{1}{2}\log_e(p/q)$, is equivalent to the r, z transformation with $r = 2p - 1$ (see Table VIII). For values of $p < 0{\cdot}5$ logits are *negative*, and numerically equal to the tabular values for $1 - p$.

TABLE VII

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L O G I T S

Weighting Coefficients and Logit Values to be used for Final Adjustments

Expected value	Working values			Weighting coefficient	Expected value	Working values			Weighting coefficient
	Minimum	Range	Maximum			Minimum	Range	Maximum	
0·00	−1·0000	2·0000	1·0000	1·00000	2·00	−25·799	28·308	2·5092	·070651
0·05	−1·0026	2·0050	1·0024	·99750	2·05	−28·620	31·178	2·5583	·064147
0·10	−1·0107	2·0201	1·0094	·99007	2·10	31·743	34·351	2·6075	·058223
0·15	−1·0249	2·0453	1·0204	·97783	2·15	−35·200	37·857	2·6568	·052831
0·20	−1·0459	2·0811	1·0352	·96104	2·20	39·025	41·732	2·7061	·047925
0·25	1·0744	2·1277	1·0533	·94001	2·25	−43·259	46·014	2·7556	·043465
0·30	−1·1111	2·1855	1·0744	·91514	2·30	47·942	50·747	2·8050	·039411
0·35	−1·1569	2·2552	1·0983	·88685	2·35	−53·124	55·978	2·8545	·035728
0·40	−1·2128	2·3375	1·1247	·85564	2·40	58·855	61·759	2·9041	·032384
0·45	−1·2798	2·4331	1·1533	·82200	2·45	65·195	68·149	2·9537	·029348
0·50	−1·3591	2·5430	1·1839	·78645	2·50	72·207	75·210	3·0034	·026592
0·55	−1·4521	2·6685	1·2164	·74948	2·55	−79·961	83·014	3·0530	·024092
0·60	−1·5601	2·8107	1·2506	·71158	2·60	−88·536	91·639	3·1028	·021825
0·65	−1·6846	2·9709	1·2863	·67319	2·65	98·018	101·17	3·1525	·019769
0·70	−1·8276	3·1509	1·3233	·63474	2·70	−108·50	111·71	3·2023	·017904
0·75	−1·9908	3·3524	1·3616	·59659	2·75	−120·10	123·35	3·2520	·016214
0·80	−2·1765	3·5774	1·4009	·55906	2·80	−132·91	136·22	3·3018	·014683
0·85	−2·3870	3·8283	1·4413	·52242	2·85	−147·08	150·44	3·3517	·013295
0·90	−2·6248	4·1074	1·4826	·48692	2·90	−162·75	166·15	3·4015	·012037
0·95	−2·8929	4·4177	1·5248	·45272	2·95	−180·07	183·52	3·4514	·010898
1·00	−3·1945	4·7622	1·5677	·41997	3·00	−199·21	202·72	3·5012	·0098660
1·05	−3·5331	5·1443	1·6112	·38878	3·05	−220·38	223·93	3·5511	·0089314
1·10	−3·9125	5·5679	1·6554	·35920	3·10	−243·77	247·38	3·6010	·0080849
1·15	−4·3371	6·0372	1·7001	·33128	3·15	−269·64	273·29	3·6509	·0073183
1·20	−4·8116	6·5570	1·7454	·30502	3·20	−298·22	301·92	3·7008	·0066242
1·25	−5·3412	7·1322	1·7910	·28041	3·25	−329·82	333·57	3·7508	·0059957
1·30	−5·9319	7·7690	1·8371	·25743	3·30	−364·75	368·55	3·8007	·0054267
1·35	−6·5899	8·4735	1·8836	·23603	3·35	−403·35	407·20	3·8506	·0049115
1·40	−7·3223	9·2527	1·9304	·21615	3·40	−446·02	449·92	3·9006	·0044452
1·45	−8·1371	10·115	1·9775	·19773	3·45	−493·19	497·14	3·9505	·0040230
1·50	−9·0428	11·068	2·0249	·18071	3·50	545·32	549·32	4·0005	·0036409
1·55	−10·049	12·121	2·0725	·16500	3·55	−602·93	606·98	4·0504	·0032950
1·60	−11·166	13·287	2·1204	·15053	3·60	−666·62	670·72	4·1004	·0029819
1·65	−12·406	14·575	2·1684	·13722	3·65	737·00	741·15	4·1503	·0026985
1·70	−13·782	15·999	2·2167	·12501	3·70	−814·79	818·99	4·2003	·0024420
1·75	−15·308	17·573	2·2651	·11381	3·75	−900·77	905·02	4·2503	·0022099
1·80	−16·990	19·313	2·3137	·10356	3·80	−995·80	1000·1	4·3003	·0019998
1·85	−18·874	21·236	2·3624	·094180	3·85	−1100·8	1105·2	4·3502	·0018097
1·90	−20·951	23·362	2·4112	·085610	3·90	−1216·9	1221·3	4·4002	·0016376
1·95	−23·251	25·711	2·4601	·077787	3·95	−1345·2	1349·6	4·4502	·0014819

Table XI1 is used in the same manner as the probit table for final adjustments (Table IX2), the working value being given by q Min. Value + p Max Value, Min Value + p Range or Max Value − q Range. If the expected value is negative interchange the tabular minimum and maximum values with change of sign. Thus with an expected value of −0·65 and p = 0·3 the working value is 0·7(−1·2863) + 0·3(1·6846) = −0·3950.

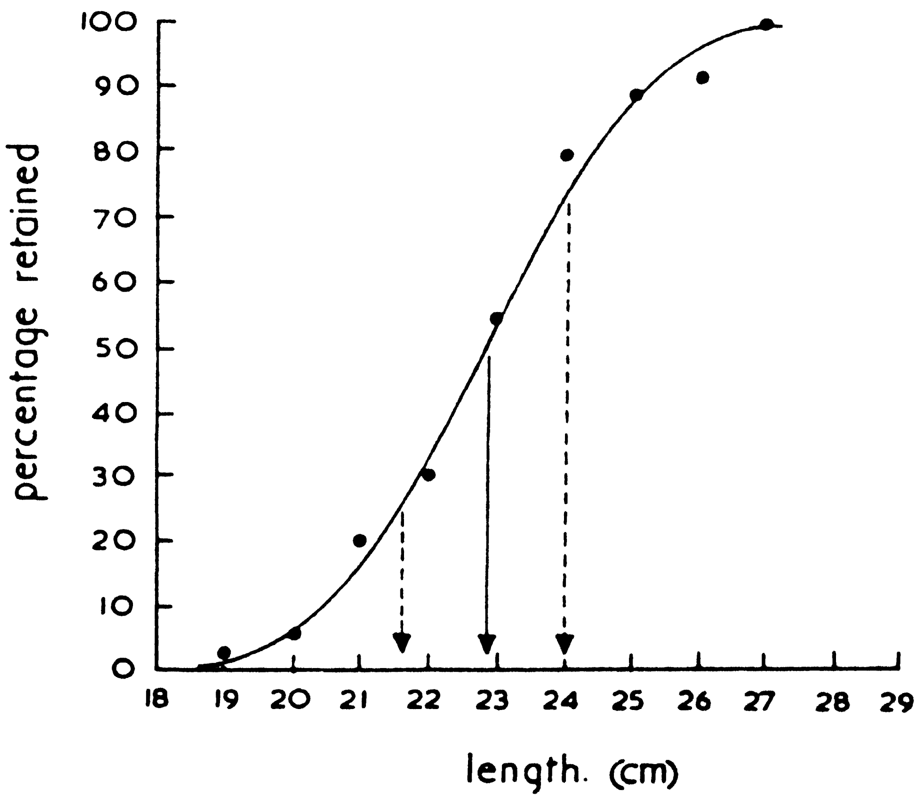


Fig. 1 Trawl cod-end mesh selection curve for haddock
(Data from Table 1)

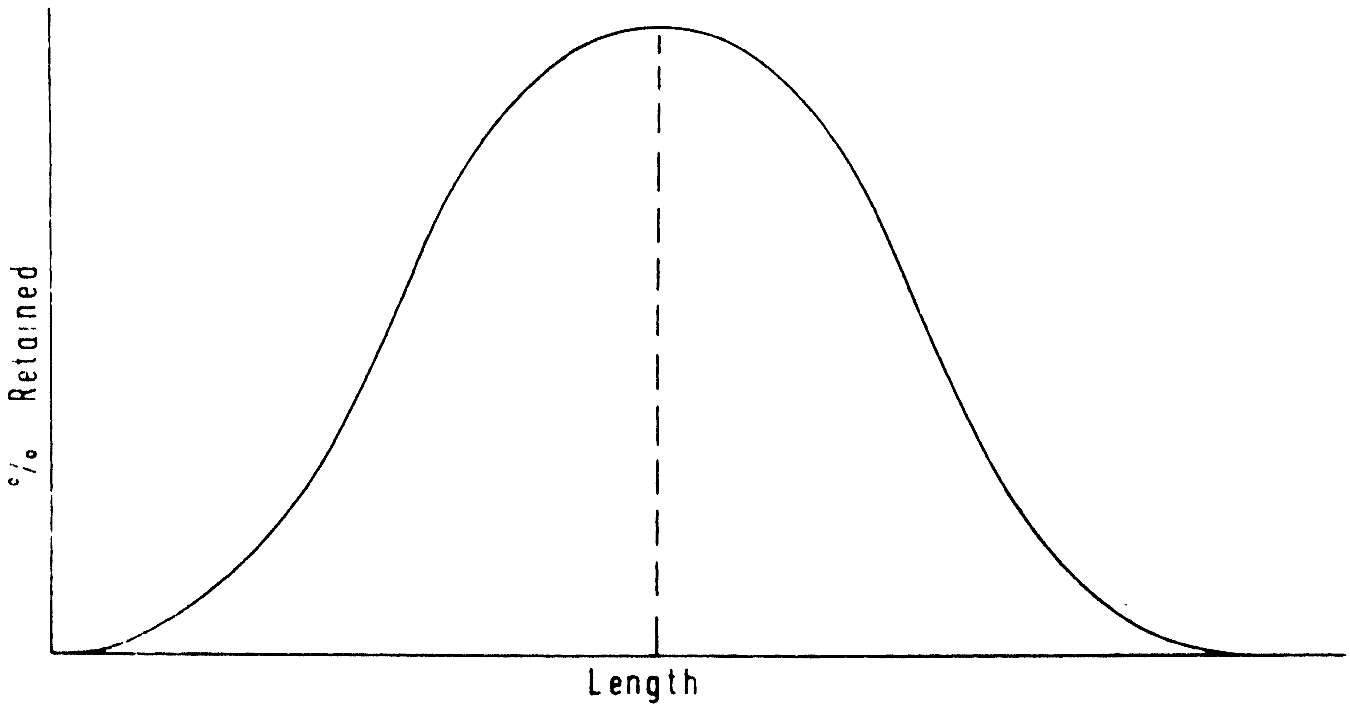


Fig. 2. Gillnet mesh selection curve

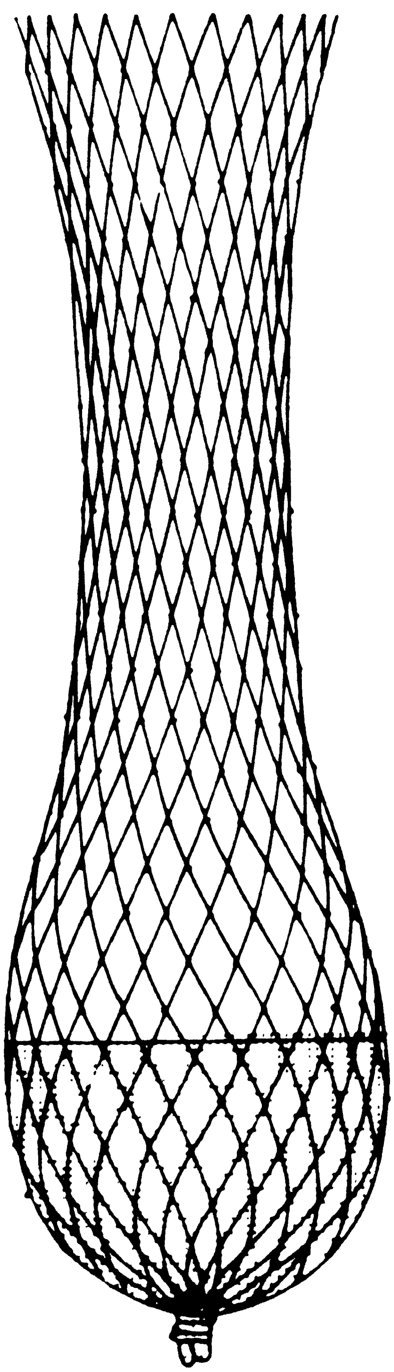


Fig. 3 Shape of trawl cod-end in action
(after Cassie 1955)

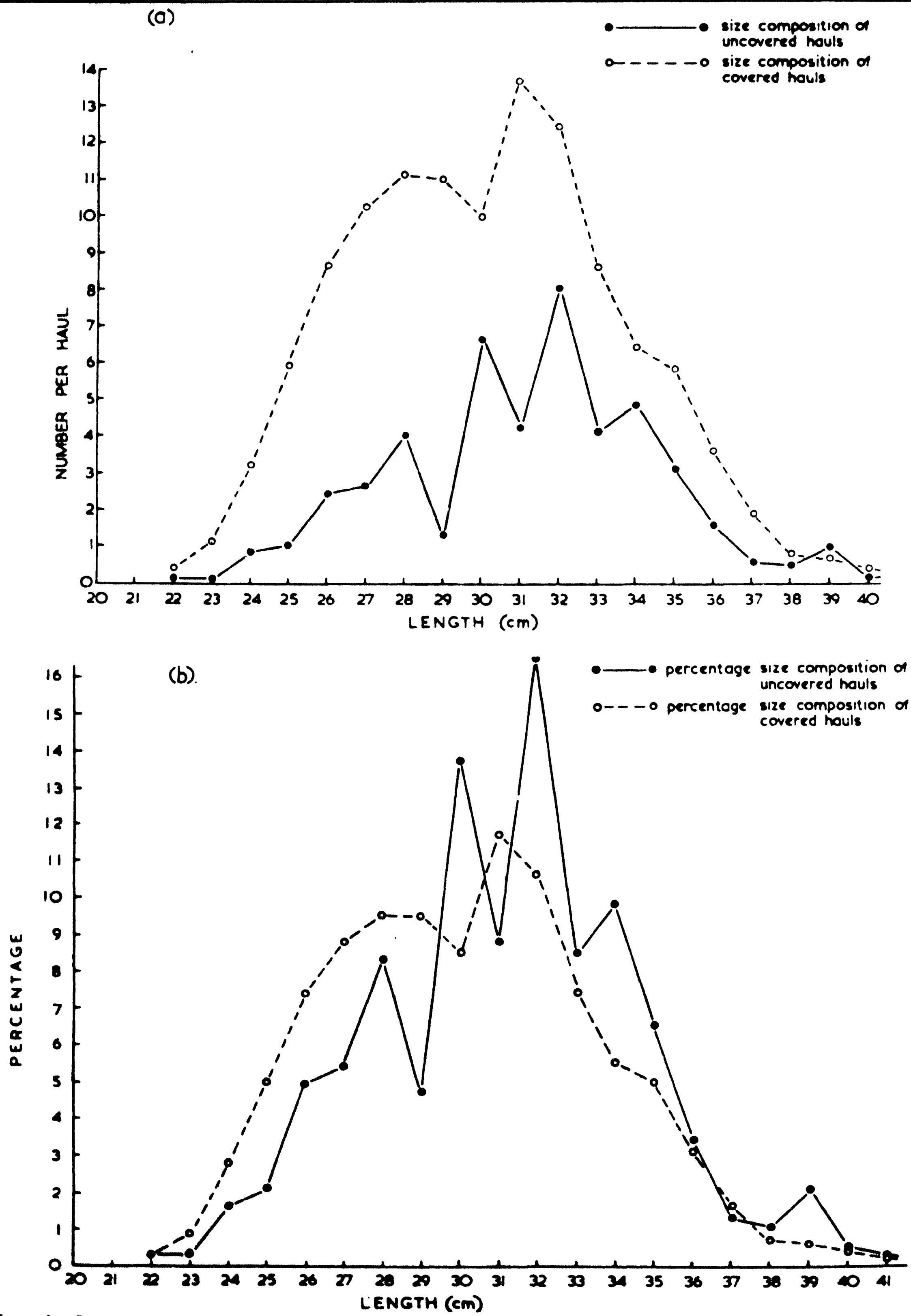


Fig. 4 Length composition of catches of whiting by covered and uncovered cod-ends, expressed as: (a) numbers per haul and (b) percentages

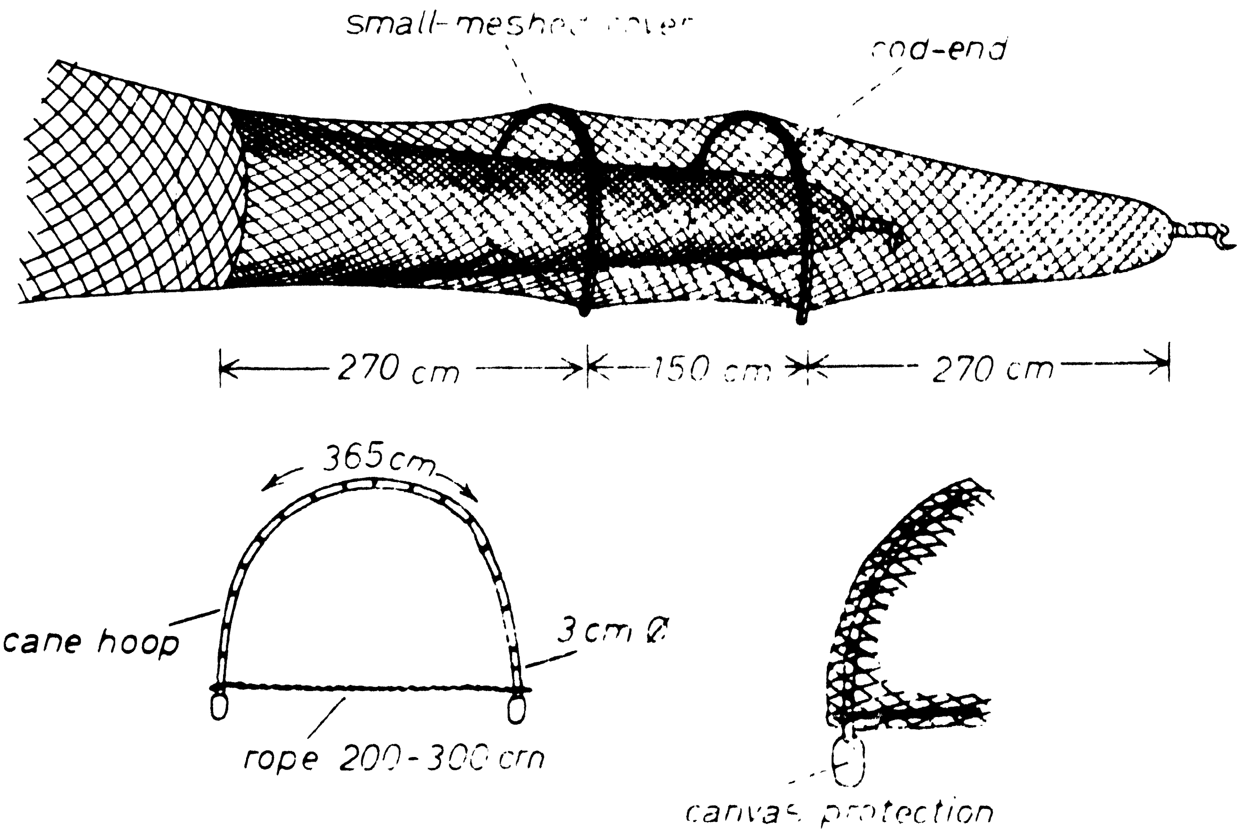
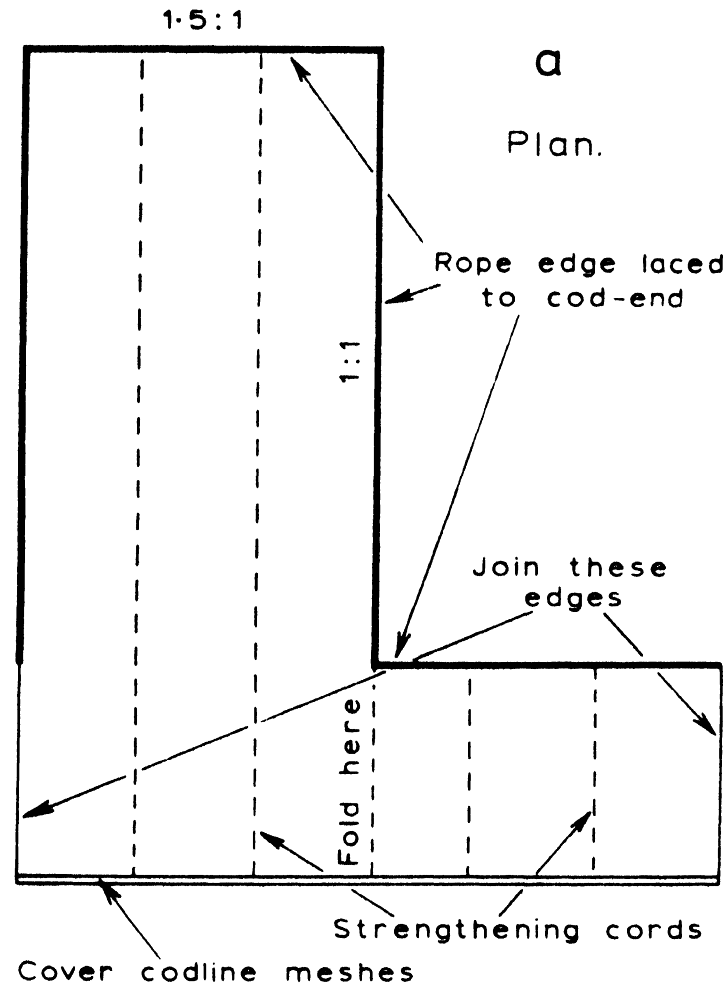


Fig. 5 Diagram of rigging of whole cod-end cover with cane hoops
(From ICES, 1964)



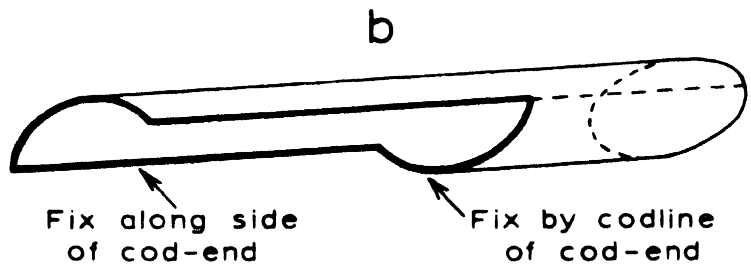


Fig. 6 Construction and fixing plan for cod-end top-side cover

(a) Small-meshed netting cut-out and construction plan. Ratios indicated are of stretched length and width, cover netting to cod-end netting

(b) Diagram of cover ready for attachment to cod-end

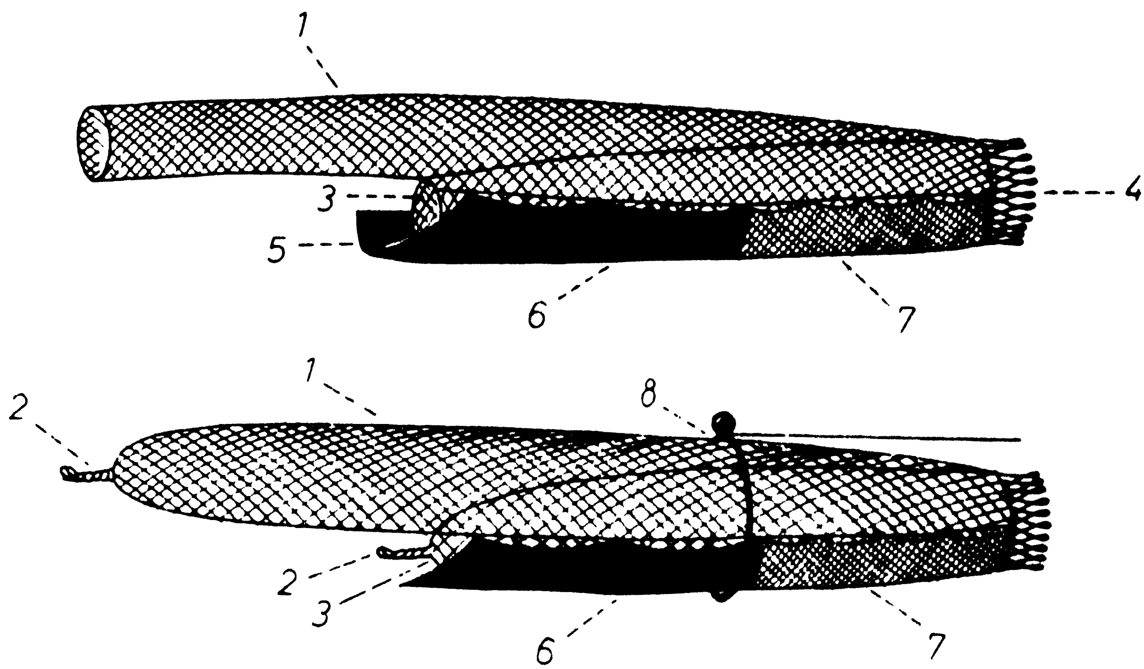


Fig. 7 Diagram of attachment of cod-end top-side cover to cod-end, showing other essential ancillary rigging of cod-end. (1) Top-side cover, (2) cover and cod-end cod-lines, (3) cod-end, (4) forward edge of cod-end with rings for quick attachment to net belly, (5) small-meshed blinder of cod-line meshes and knot, (6) hide chafer beneath cod-end, (7) small-meshed blinder on inside of bottom side of cod-end, (8) splitting strop with float. (From ICES, 1964)

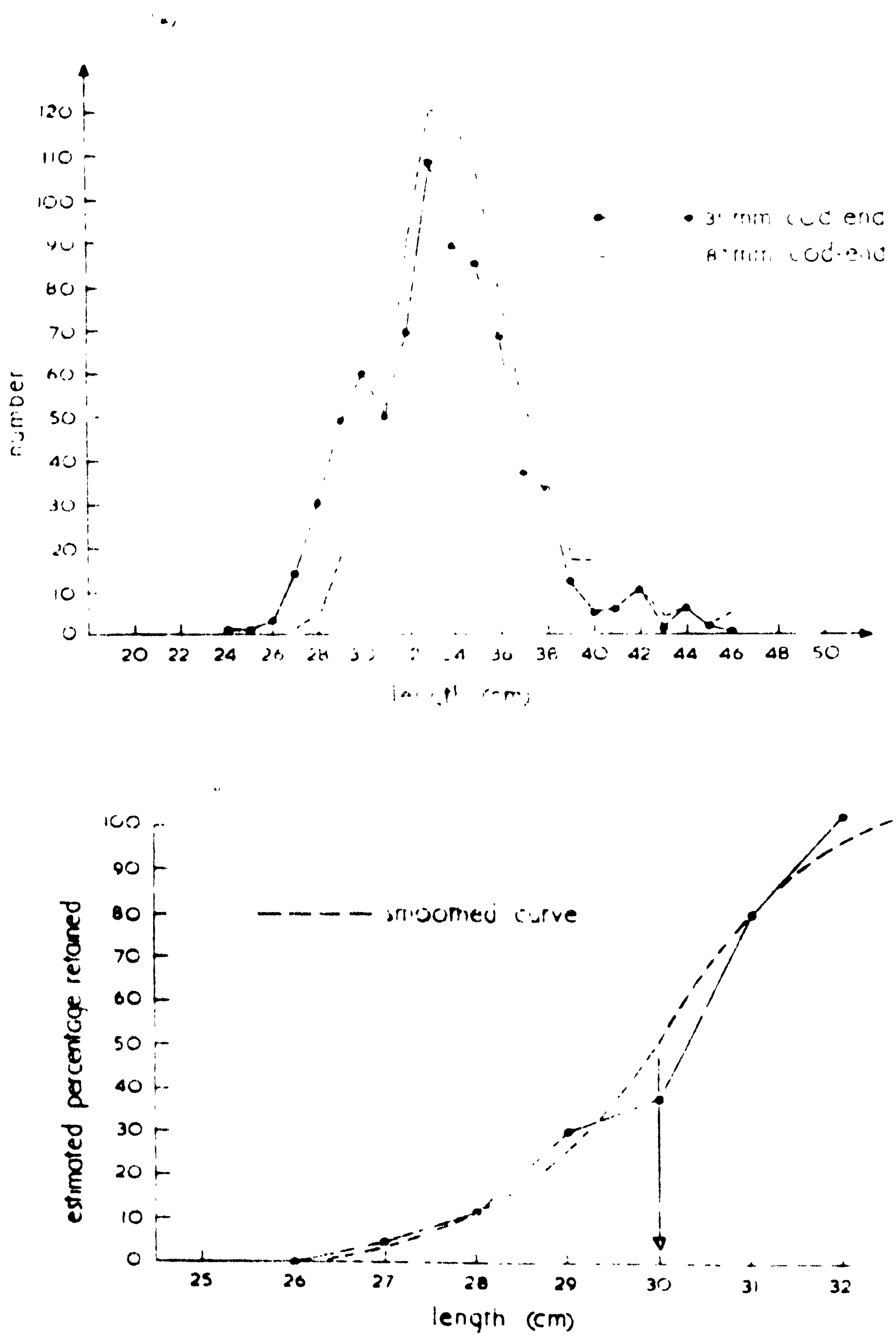


Fig. 8 Trawl cod-end selectivity measurement by alternate haul method for haddock in an 87 mm polypropylene cod-end

(a) Length composition of small and large mesh catches

(b) Selection curve

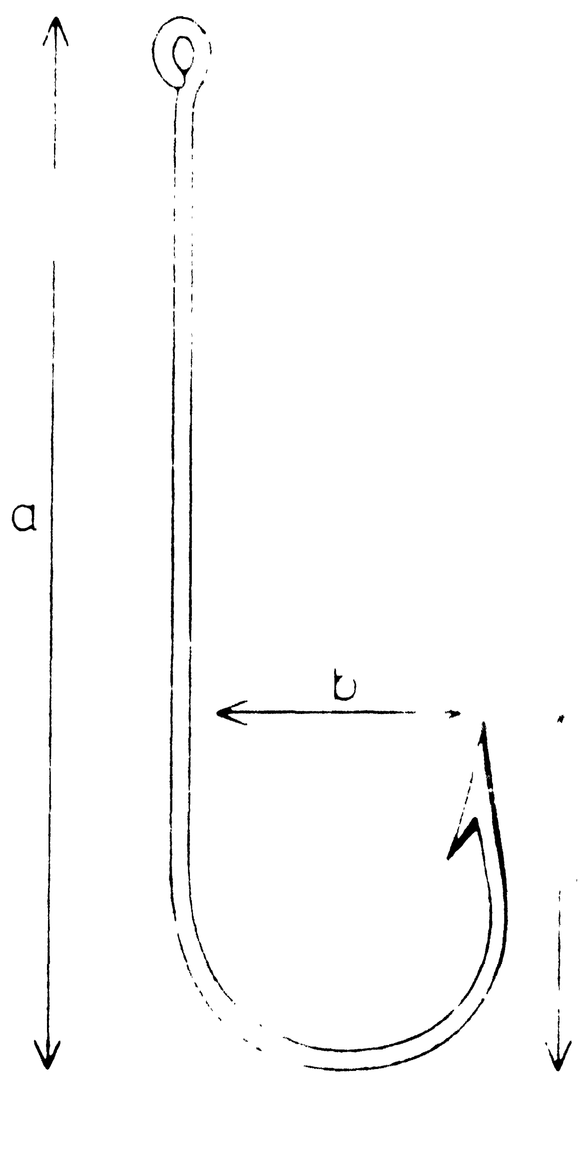


Fig. 9 Hook, showing essential size measurements:
(a) shank length, (b) gape, (c) point length

Fig. 10 ICES mesh gauge being used to measure mesh size

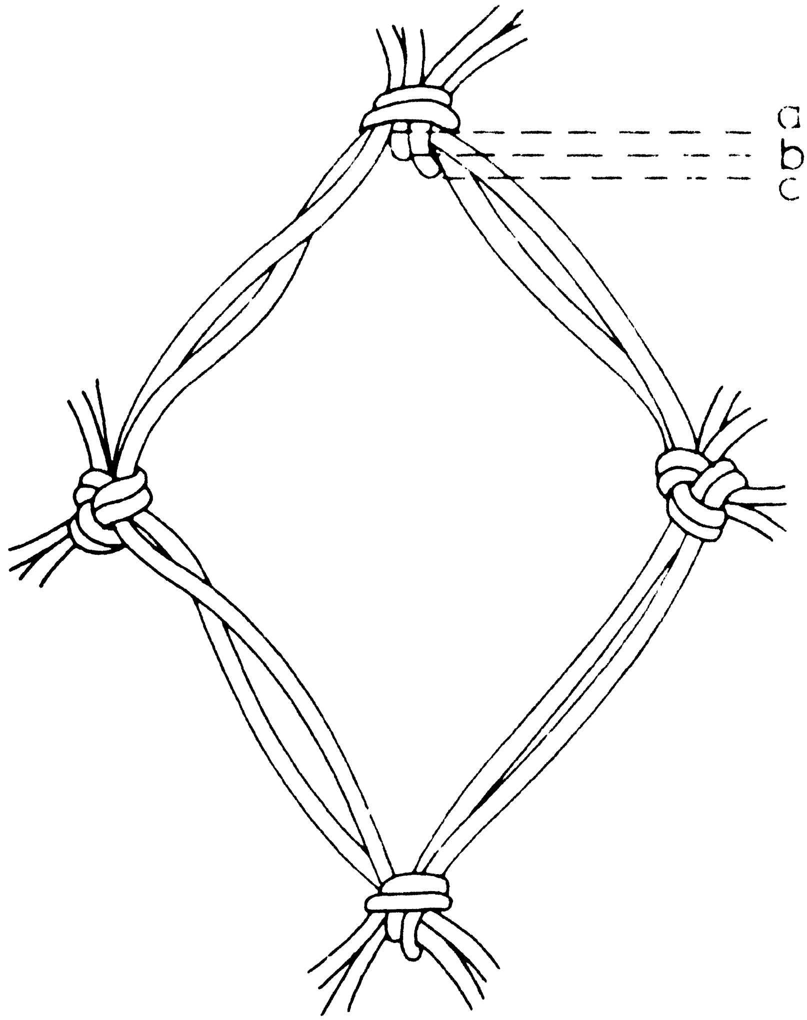


Fig. 11 Sketch of double-braided mesh showing three possible positions (a, b and c) for lodgement of gauge

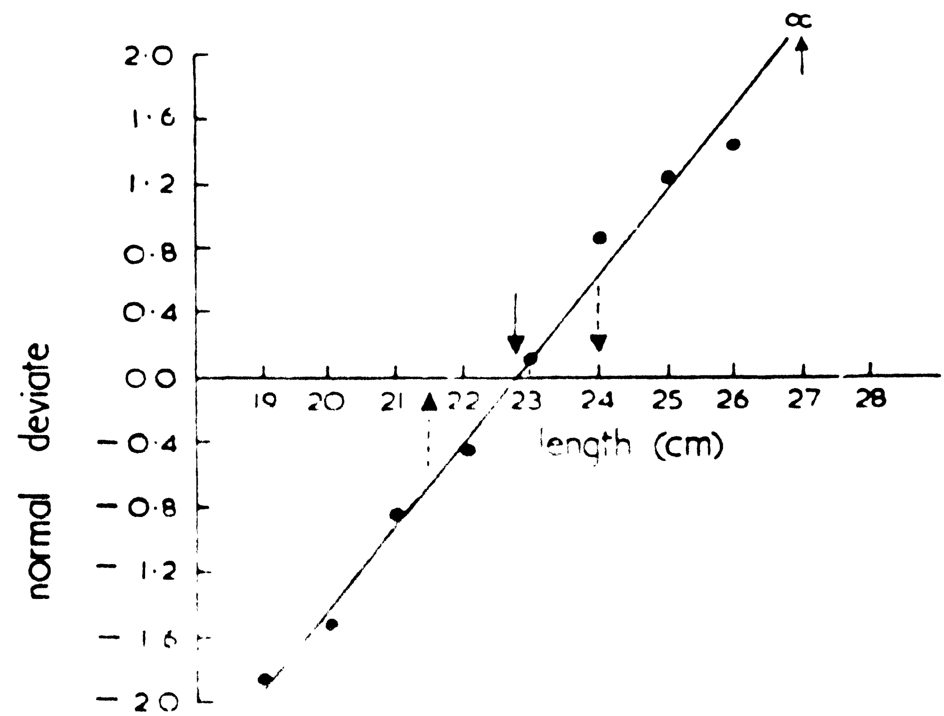


Fig. 12 Selection curve for table [illegible] fitted after transformation to normal deviates

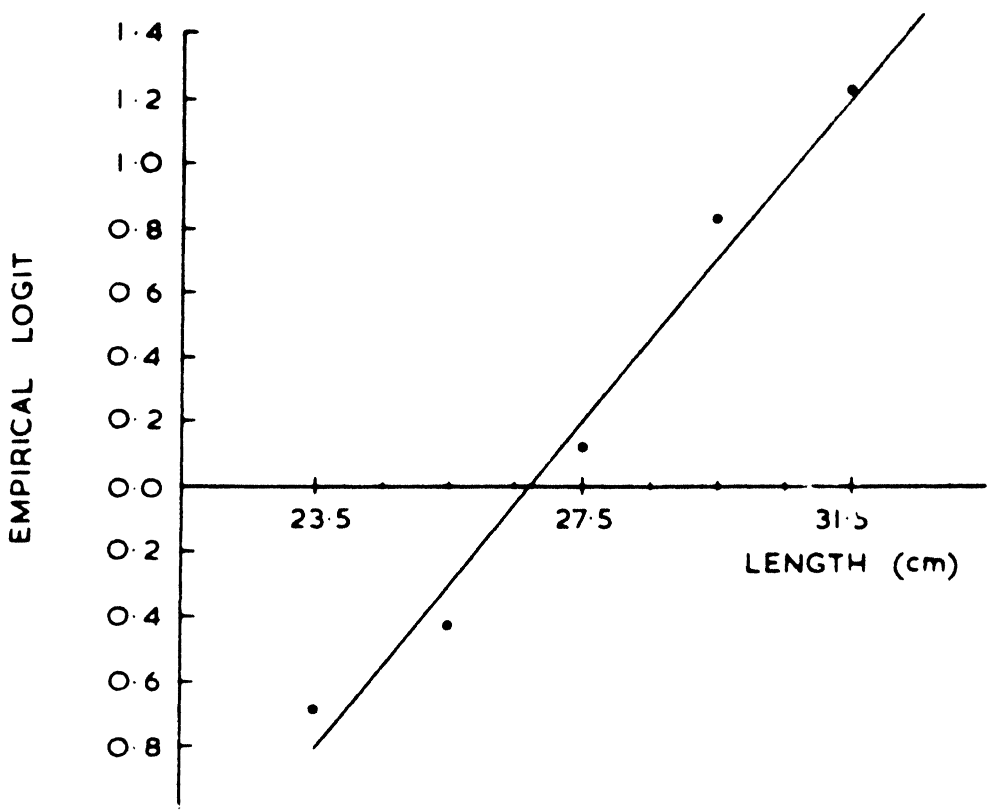


Fig. 13 Fitting of logistic selection curve

No: 11198

no: 11198

65 + 15

80